Monographs on
Surgery • 1952

MONOGRAPHS ON SURGERY • 1952

B. NOLAND CARTER, M.D., Ph.D.

Editor

Professor of Surgery, University of Cincinnati
Director of the Surgical Services,
Cincinnati General Hospital

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GYNECOLOGY

JOE V. MEIGS, M.D.

Clinical Professor of Gynecology, Harvard University Medical School; Chief of the Vincent Memorial Hospital

UROLOGY

CHARLES HUGGINS, M.D.

Professor of Urology, the University of Chicago; Chairman of Committee on Cancer, the University of Chicago

ORTHOPEDIC SURGERY

ALFRED R. SHANDS, M.D.

Medical Director, Alfred I. duPont Institute of the Nemours Foundation

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Introduction

This is the third volume of Monographs on Surgery which has been offered to the surgical profession. These volumes have replaced the previously published Nelson's Loose Leaf Surgery.

The manner in which these volumes has been received leaves little doubt that the change of policy, from the publication of a system of surgery with annual supplements to that of a yearly volume containing chapters on pertinent and proved surgical subjects, has been a happy one. Among other advantages, it would appear that the addition to the surgeon's library of these yearly volumes should result in the eventual acquisition of a valuable set of reference books on surgical subjects, both important and timely.

Radical surgery of the pancreaticoduodenal region was revived by Whipple and his associates seven years ago, and has been practiced widely since that time. It therefore seemed of interest to present here an evaluation of this type of surgery. From his rich background of experience, Doctor Whipple has outlined his ideas concerning the proper place for this method of treatment.

The management of injuries of the thorax is assuming a more important place in surgery, owing not only to the military situation but also to the large number of industrial and automobile accidents occurring in civilian life. Doctor Brian Blades has had an unusual opportunity to observe a tremendous number of such injuries, and has written a concise and practical chapter on this subject.

Considerable discussion has been carried on in recent years concerning the use of radioactive iodine in the treatment of thyroid disease. On one hand, the use of this material has been strongly advocated, both for treatment and diagnosis; while on the other, it has been condemned. Doctor George Curtis, a pioneer in this field, has presented, clearly and simply, his evaluation of the proper use of radioactive iodine, in the management of diseases of the thyroid.

One of the most distressing conditions with which gynecologists have to deal is that of stress urinary incontinence. The group of six articles on this subject by Doctors Muellner, Kennedy, Frost, Aldridge, Kegel, and Ingleman-Sundberg represents the best opinions in the field on this subject. As Doctor Meigs has stated in his introduction to that section, these articles should do much toward clarifying the best approach to this difficult problem.

The orthopedic section, under the editorship of Doctor Alfred Shands, maintains the high standard attained in the previous volumes. Doctor Cooper's article, "Aseptic Necrosis of the Femoral Head in Adults," deals with a condition of growing importance. His article is comprehensive but concise. Doctor Knight has written an excellent treatise on "Arthroplasty," in which he discusses in

detail the types of operative procedures and their relative values. The third article in the orthopedic section, by Doctors Schottstaedt, Larsen and Bost, is a timely one and deals with intracapsular fractures of the femoral neck. The management of this difficult type of fracture is carefully detailed, and many pertinent technical points are stressed. The authors have made a valuable contribution to the subject under discussion. The internal fixation of fractures of the shaft of long bone has come into vogue within the past eight or ten years, and this method of treatment may now be discussed authoritatively. Doctor Eggers has handled this subject in excellent fashion, and his monograph should be read with much interest by all those concerned with methods of managing various types of fractures.

The section on urology contains two articles dealing with conditions which are of interest to the general surgeon, as well as to urologists. Doctor Whitmore has written interestingly and well on the subject of renal neoplasms. An excellent classification of tumors of the kidney is given, the pathological aspects of the tumors are reviewed, and present-day methods of diagnosis and treatment are outlined. Doctor Hinman's scholarly presentation, "Congenital Ureteral and Pelvic Dilatation as Evidence of Obstruction," should prove both interesting and instructive.

The surgery of the large arteries has been undergoing considerable change in recent years. The visualization of blood vessels by injection of contrast media, the improved methods of arterial suture, the use of vein transplants and the ability to use shunting procedures have all contributed to this change. The subject is such a large one that Doctor Freeman considered it practical to treat it in two parts. His contribution to the present volume deals with general principles based on a historical background and, in addition, with arteriography and other newer developments in the field of vascular surgery. In the next volume of MONOGRAPHS ON SURGERY, Doctor Freeman will complete his discussion of this important topic.

The editor takes this opportunity to express his thanks to the associate editors, Doctors Meigs, Shands, and Huggins, for their interest and co-operation and for obtaining such excellent articles from outstanding members of their various specialties. His thanks also go to the authors of the various monographs which comprise this volume, and to the publishers for their willingness to contribute so generously to its success.

B. NOLAND CARTER, M. D.

Contributors

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Albert H. Aldridge, M.D.: Clinical Professor of Obstetrics and Gynecology, College of Physicians and Surgeons, Columbia University; Chief Surgeon, Woman's Hospital, New York.

Brian Blades, M.D.: Professor of Surgery, George Washington University School of Medicine, Washington, D. C.

Frederic C. Bost, M.D.: Clinical Professor, University of California School of Medicine; Chief Surgeon, Shriners' Hospital, San Francisco.

William Cooper, M.D.: Attending Orthopaedic Surgeon, Hospital for Special Surgery, New York.

George M. Curtis, M.D., Ph.D.: Professor of Surgery, Ohio State University; Chief of Research Surgical Service, Ohio State University Hospital, Columbus.

G. W. N. Eggers, M.D.: Professor of Orthopedic Surgery, University of Texas School of Medicine, Galveston.

Norman E. Freeman, M.D.: Associate Clinical Professor of Surgery, University of California; Director, Vascular Research Laboratory, Franklin Hospital; Consultant in Vascular Surgery, Letterman Army Hospital and Fort Miley Veterans Hospital, San Francisco.

Inglis F. Frost, M.D.: Chief, Endocrine Clinic, Woman's Hospital, New York.

Tom M. Fullenlove, M.D.: Clinical Instructor in Radiology, University of California School of Medicine; Radiologist, Franklin Hospital, San Francisco.

R. Carl Garby, M.D.: Instructor in Surgery, George Washington University School of Medicine, Washington, D. C.

Rutherford S. Gilfillan, M.D.: Clinical Instructor in Surgery, University of California Medical Center; Assistant Director, Vascular Research Laboratory, Franklin Hospital, San Francisco.

Frank Hinman, Jr., M.D.: Assistant Clinical Professor of Urology and Acting Chairman, Department of Surgery-Urology, University of California School of Medicine, San Francisco.

Axel Ingelman-Sundberg, M.D.: Assistant Professor of Obstetrics and Gynecology, Caroline Institute, the University of Stockholm; Assistant Chief, Department of Obstetrics and Gynecology of the Carolina Institute, Sabbatsbergs Hospital, Stockholm.

Arnold H. Kegel, M.D.: Assistant Clinical Professor of Gynecology, University of Southern California; Attending Staff, Los Angeles County General Hos-

pital; Attending Surgeon, Hollywood Presbyterian and Olmstead Memorial Hospitals, Los Angeles.

William T. Kennedy, M.D., M.A.: Consulting Surgeon, Woman's Hospital and Booth Memorial Hospital, New York.

Robert A. Knight, M.D.: Assistant Professor of Orthopedic Surgery at the University of Tennessee College of Medicine; Attending Orthopedic Surgeon, Campbell Clinic, Memphis, Tenn.

Loren J. Larsen, M.D.: Assistant Clinical Professor, University of California School of Medicine; Assistant Surgeon, Shriners' Hospital, San Francisco.

Frank H. Leeds, M.D.: Franklin Hospital, San Francisco.

Charles V. Meckstroth, M.D., M.M.Sc.: Instructor in Research Surgery, Ohio State University; Resident on the Research Surgical Service, Ohio State University Hospital, Columbus.

S. Richard Muellner, M.D.: Assistant Professor of Urology, Tufts College Medical School; Instructor in Urology, Harvard University Medical School; Assistant Visiting Urologist, Beth Israel Hospital, Boston.

Edwin R. Schottstaedt, M.D.: Assistant Clinical Professor, University of California School of Medicine; Assistant Chief Surgeon, Shriners' Hospital, San Francisco.

Allen O. Whipple, M.D.: Clinical Director, Memorial Hospital, New York.

Willet F. Whitmore, M.D.: Assistant Professor of Clinical Surgery (Urology), Cornell University Medical College; Attending Surgeon in Urology, Memorial Center; Assistant Attending Surgeon (Urology), New York Hospital, New York.

1951

Joe M. Blumberg, M.D.: Lt. Col., M.C, U.S.A., Pathologist, Walter Reed Army Hospital, Army Medical Center, Washington, D.C.

Edwin F. Cave, M.D.: Chief, Fracture Service and Visiting Orthopedic Surgeon, Massachusetts General Hospital; Associate in Orthopedic Surgery, Harvard Medical School, Boston.

Murray M. Copeland, M.D.: Professor of Oncology, Director of Department of Oncology, Georgetown University Medical Center, Washington, D.C.

Charles F. Geschickter, M.D.: Professor of Pathology, Georgetown University Medical School; Consultant in Pathology, U. S. Naval Medical School, Bethesda, Md.; Consultant in Pathology, Mt. Alto Veterans Administration Hospital; Pathologist-in-Chief, Gallinger Municipal Hospital, Washington, D.C.

Ruth M. Graham: Research Associate in Surgery; Instructor in Cytology, University of Oregon Medical School, Portland, Ore.

Stuart W. Harrington, M.D.: Division of Surgery, the Mayo Clinic, Rochester, Minn.

Peter A. Herbut, M.D.: Professor of Pathology, Jefferson Medical College, Philadelphia.

Charles Huggins, M.D.: Professor of Urology, the University of Chicago; Chairman of Committee on Cancer, the University of Chicago, Chicago.

Frank P. Kreuz, M.D., Capt., M.C., U.S.N.: Chief of the Department of Orthopaedics, U. S. Naval Hospital, National Naval Medical Center, Bethesda, Md.

Leland S. McKittrick, M.D.: Clinical Professor of Surgery, Harvard Medical School; Visiting Surgeon, Massachusetts General Hospital; Surgeon-in-Chief, Palmer Memorial Hospital, Boston.

Stanley H. Moulton, M.D.: Instructor in Surgery, Department of Surgery (Urology), University of Chicago, Chicago.

Philip F. Partington, M.D.: Assistant Clinical Professor of Surgery, Western Reserve University Medical School; Formerly Chief, Surgical Service, Crile Veterans Administration Hospital, Cleveland.

Edgar R. Pund, M.D.: Professor of Pathology, Medical College of Georgia; Chief Pathologist, University Hospital; Consultant Pathologist, Oliver General (U. S. Army) Hospital, Augusta, Ga.

Abraham E. Rakoff, M.D.: Clinical Professor of Obstetrics and Gynecologic Endocrinology; Endocrinologist, Jefferson Hospital Laboratories, Jefferson Medical College, Philadelphia.

Thomas S. Risley, M.D.: Assistant in Surgery, Massachusetts General Hospital; Clinical Assistant in Surgery, New England Deaconess Hospital, Boston.

Maurice D. Sachs, M.D.: Senior Instructor in Radiology, Western Reserve University School of Medicine; Chief, Radiology Service, and Director, Radioisotope Unit, Veterans Administration Hospital, Cleveland.

Alfred R. Shands, Jr., M.D.: Medical Director, Alfred I. duPont Institute of the Nemours Foundation, Wilmington, Del.; Visiting Professor of Orthopaedic Surgery, University of Pennsylvania School of Medicine, Philadelphia.

Fred A. Simmons, M.D.: Assistant Surgeon, Massachusetts General Hospital; Instructor in Gynecology, Harvard Medical School; Assistant Surgeon to Outpatients, Free Hospital for Women, Boston.

Alan DeF. Smith, M.D.: Professor of Orthopaedic Surgery, College of Physicians and Surgeons, Columbia University; Director, New York Orthopaedic Hospital, New York.

Richard W. TeLinde, M.D.: Gynecologist in Chief, the Johns Hopkins Hospital; Professor of Gynecology, the Johns Hopkins University, Baltimore.

Howard Ulfelder, M.D.: Clinical Associate in Gynecology, Harvard Medical School; Assistant Surgeon, Massachusetts General Hospital; Gynecologist, Pondville Hospital, Boston.

Paul A. Younge, M.D.; Instructor, Department of Gynecology, Harvard Medical School; Visiting Surgeon, Free Hospital for Women, Boston.

1950

William A. Altemeier, M.D.: Department of Surgery, College of Medicine of the University of Cincinnati; Cincinnati General Hospital, Cincinnati.

Lenox D. Baker, M.D.: Professor of Orthopaedic Surgery, Duke University School of Medicine, Durham, N. C.

Leonard F. Bush, M.D.: Chief of the Orthopaedic Service, Geisinger Memorial Hospital, Danville, Pa.

Richard Chute, M.D.: Associate Visiting Urologist, Massachusetts General Hospital; Assistant in Genito-Urinary Surgery, Harvard University Medical School, Boston.

Paul C. Colonna, M.D.: *Professor of Orthopaedic Surgery, School of Medicine,* University of Pennsylvania, Philadelphia.

Michael E. DeBakey, M.D.: Department of Surgery, Baylor University College of Medicine, Houston, Texas.

Paul DeCamp, M.D.: Department of Surgery, School of Medicine, Tulane University of Louisiana; Ochsner Clinic, New Orleans.

Z. B. Freidenberg, M.D.: Instructor in Orthopaedic Surgery, School of Medicine, *University of Pennsylvania, Philadelphia.*

C. Zent Garber, M.D.: Pathologist, New York Orthopaedic Hospital; Assistant Professor, College of Physicians and Surgeons, Columbia University.

Walter A. Hoyt, Jr., M.D.: Orthopaedic Fellow, National Foundation for Infantile Paralysis; Instructor in Orthopaedic Surgery, Duke University School of Medicine, Durham, N. C.

John S. Moore, M.D.: Senior Resident in Orthopaedic Surgery, Hospital of the *University of Pennsylvania, Philadelphia.*

Alton Ochsner, M.D.: Department of Surgery, School of Medicine, Tulane University of Louisiana; Ochsner Clinic, New Orleans.

Langdon Parsons, M.D.: Professor of Gynecology, Boston University School of Medicine; Visiting Surgeon, Massachusetts Memorial Hospital; Surgeon, Palmer Memorial Hospital; Visiting Surgeon, Pondville Hospital, Walpole, Mass.

William W. Scott, M.D., Ph.D.: Professor of Urology, Johns Hopkins University School of Medicine; Urologist in Charge, the Johns Hopkins Hospital, Baltimore.

Vinton E. Siler, M.D.: Assistant Professor of Surgery, College of Medicine, University of Cincinnati; Attending Surgeon, Cincinnati General Hospital, the Children's Hospital and the Christian R. Holmes Hospital, Cincinnati.

Dana M. Street, M.D.: Chief, Orthopaedic Section, Veterans Administration Medical Teaching Group, Kennedy Hospital, Memphis, Tenn.

John H. Wulsin, M.D.: Assistant Resident in Surgery, Cincinnati General Hospital, Cincinnati.

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The Radical Surgery of Pancreaticoduodenal Cancer

ALLEN O. WHIPPLE, M.D.

INTRODUCTION

Every operation for the radical removal of cancer, in its different anatomic sites, has undergone various modifications, by trial and error, before it has proved its worth and before the late favorable results have warranted its acceptance by the surgical profession. In recent years, factors such as improved methods of general, local, spinal, and intravenous anesthesia, the adequate supply and intelligent use of blood for transfusion before, during, and after operation, the better understanding of the importance of maintaining fluid and electrolyte balance, and the discriminating use of the antibiotics and chemotherapeutic agents have made radical surgical procedures possible that 20 or 30 years ago were not thought of or were considered prohibitively hazardous.

Intratracheal anesthesia and antibiotic therapy have made possible pneumonectomy and esophagectomy for cancer. Transfusion and the antibiotics have increased the safety and feasibility of such procedures as pelvic exenteration and hemipelvectomy. The proper use of preoperative and postoperative antibiotics has largly removed the hazard of peritonitis following colonic and rectal surgery. Furthermore, these adjuvants to surgery have made possible one stage procedures that formerly were considered mandatory two stage operations.

But it must also be said that improvements in technic, the better understanding of minimal trauma, complete hemostasis, which was so ably taught by Halsted and which has become more generally known by the term "fine silk technic," have been tremendous factors in increasing the feasibility of much of the radical surgery of today and have reduced the hazard of necessarily prolonged procedures.

This evolution of a radical operation for cancer is well illustrated in the attack on the growths occurring in the ampullary area, the duodenum, and the pancreas which has developed since 1935, when the renewed attempts began to be reported (Whipple, Parsons, and Mullins). The above mentioned ancillary factors, together with the many modifications since reported, have established the radical surgery for these tumors.

The structures comprising the lower end of the common duct, the papilla of Vater, the pancreas, and the duodenum, may be spoken of as the pancreaticoduodenal area, and the cancers involving these structures as pancreaticoduodenal cancers. These cancers have much in common in the insidious onset of their symptoms. These are usually confused with digestive disturbances and biliary disorders and are generally treated conservatively and symptomatically for in-

definite periods. Because of the delayed diagnosis, these carcinomas have in the past been explored late or discovered at autopsy, giving the internists first to be consulted, and the medical profession at large, a pessimistic attitude regarding them.

In recent years, it has been demonstrated that the structures in the pancreaticoduodenal area can be removed en bloc and that cancers of any one of these structures can be dealt with by the same radical procedure of pancreaticoduodenectomy. However, the success of this procedure in removing the cancer while still localized to any one of the structures in the pancreaticoduodenal area depends entirely on early diagnosis—a diagnosis which must be promptly made by the clinician first studying the patient.

It is now 16 years since a renewed surgical attack was made in excising a carcinoma of the papilla of Vater, by removing the lower end of the common duct, a portion of the head of the pancreas, and a sleeve of the duodenum, including the papilla (Whipple, Parsons, and Mullins). A year later, the writer removed the entire duodenum as well as the lower end of the common duct and the head of the pancreas for a carcinoma of the papilla of Vater. This, as well as the first case, was done in two stages. Since then, many modifications of the two and one stage radical pancreaticoduodenectomies have been reported and several hundred of these various procedures have been done, many of them reported in fairly large series from several of the best American surgical clinics. It is therefore now possible to evaluate the results of the radical procedures for cancer of the several structures in the pancreaticoduodenal area, and to determine certain of the surgical principles which are common to the several modifications and which should be followed to accomplish the best results.

But first it is advisable to review the history of this type of surgery as a background, and to explain the evolution of the present-day radical procedures dealing with these cancers.

The earlier attempts to excise locally a carcinoma of the papilla of Vater were unsuccessful, both in the immediate and the late results, as shown in a review by Hunt. In this he pointed out that in 109 such operations, there were 34 postoperative deaths (31.1 per cent), and that 12 patients, or 14 per cent, survived the operation and were living for periods of three to 22 years—one such case. These earlier attempts to remove the tumor locally were largely the result of the belief, then prevalent, that the duodenum was essential to life and could not be excised. The first of these local excisions was carried out by William S. Halsted on a 60 year old woman, in February, 1898. His description states: "To give the growth a wide margin, a large piece of the duodenum was excised—a wedge-shaped piece with the apex at the mesenteric border of the intestine. About three quarters of an inch of the common duct and a shorter piece of the pancreatic duct were excised. The wound in the duodenum was closed in the usual way with mattress sutures [of silk?]. This was practically an end-to-end anastomosis of the duodenum. The common duct and the pancreatic duct were transplanted into the duodenum along the line of suture." This patient lived for six months but then developed, and died of, a recurrence in the pancreas.

In 1899, Riedel carried out an even less radical local excision through a duodenotomy. Rixford in the same year reported a procedure much like Halsted's,

and in the course of the next decade, six or more similar procedures were reported by as many different surgeons.

A more radical operation was done in 1898 for the first time by Codivilla. He did a subtotal removal of the duodenum, a portion of the head of the pancreas, completing the operation with a cholecystojejunostomy, a gastrojejunostomy, and a jejunojejunostomy. This patient survived the operation for a period of 24 days but the cause of death was not given.

In 1907, Desjardins described a radical operation of the head of the pancreas and duodenum in a two stage procedure, as carried out on the human cadaver. He proposed implanting the stump into the jejunum. In 1908, Sauvé described a one stage procedure, with several variations, and advised bringing the transected neck of the pancreas into the laparotomy wound to establish a pancreatic fistula. These studies were also done on cadavers. In 1909, Coffey and, in 1914, Kehr proposed resections with implantations of the pancreatic stump into the distal end of the resected duodenum. But from their reports, Desjardins, Sauvé, Coffey, and Kehr did not perform these procedures on clinical cases, yet their proposals are indicative of the desire to carry out more radical surgery. Kehr implied in his comments that many failures would be necessary before the operation would prove successful. "But the time will come when such a technical triumph will be achieved."

The prevalent impression among surgeons during the first two decades of the present century, that the duodenum and the external secretion of the pancreas were essential to life, probably prevented those dissatisfied with the results of local excision of ampullary cancers from carrying out a more radical procedure, although Kausch, in 1909, Hirschel, in 1914, and Tenani, in 1922, removed portions of the duodenum, the lower end of the common duct, and a part of the pancreatic head with reimplantation of the pancreatic stump or the pancreatic duct into the remains of the duodenum.

In analyzing the results of these earlier attempts at ampullary surgery, one finds that there were three serious postoperative complications: hemorrhage, duodenal fistula, and peritonitis. Undoubtedly the chief cause of these complications was the use of absorbable catgut. In the presence of pancreatic ferments and duodenal juices, the catgut was rapidly digested, resulting in the complications mentioned. These operations carried out in the presence of jaundice and delayed blood clotting favored hemorrhage and shock, not prevented or corrected by modern intravenous therapy.

In May 1934, the writer operated on a patient with a history of gradually increasing painless jaundice. A tumor of the papilla of Vater was found and excised by the transduodenal route, uniting the dilated common duct and pancreatic duct to the duodenostomy. Catgut was used in this procedure. The patient developed a duodenal leak with secondary hemorrhage and a diffusing peritonitis and died 30 hours after the operation. Autopsy showed that the chromic catgut used for ligatures and sutures had been digested.

During the previous year, we had removed islet cell tumors from the pancreas, using fine silk in the operations. Doctor Mullins, then our senior resident, urged us to use this silk technic for the next patient coming in with an ampullary cancer. In August 1934, a man with a history of painless jaundice and palpable gall-

definite periods. Because of the delayed diagnosis, these carcinomas have in the past been explored late or discovered at autopsy, giving the internists first to be consulted, and the medical profession at large, a pessimistic attitude regarding them.

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During the period of 1935-1945, a number of surgeons reported their modifications of the two stage procedure, notably Orr, Hunt, Cooper, and Illingworth. In 1937, Nemenyi reported a one stage procedure similar to the technic employed by Kausch in two stages, but neither of these surgeons did a total duodenectomy. In 1940, Hunt and Mahoney carried out one stage radical procedures. Brunschwig, in 1937, was the first to perform successfully a radical pancreaticoduodenectomy for carcinoma of the head of the pancreas, and since then he has been one of the most daring and able protagonists of the radical surgery of the pancreas. His textbook on this subject is very comprehensive.

At the 52nd annual meeting of the Western Surgical Association in 1944, Orr presented a comprehensive review of the cases of pancreaticoduodenectomy for carcinoma of the ampullary area, including 9 of his own cases. He gave 50 references in his bibliography. In this paper he discussed the diagnosis at operation, the justification for the radical procedures, the advisability of anastomosing the cut end of the pancreas to the jejunum, the choice of the one or two stage procedure, and the choice of the several technics reported up to that time. At the same meeting, Cole and Reynolds discussed the radical operation and presented the technic of a modified one stage procedure with a review of their 5 cases.

Since then, there have been many modifications (Pearse) in the technic of the two stage and one stage radical procedures, with comprehensive reviews of fairly large series from a number of leading surgical clinics, notably reports from the Mayo Clinic by Waugh, from the Lahey Clinic by Cattell, from the Memorial Hospital by Brunschwig, from the Cornell-New York Clinic by Child, and from the Columbia-Presbyterian Clinic (Frantz). A summary of the 243 cases from these five clinics is given in Table I.

TABLE I

SUMMARY OF RADICAL PANCREAS OPERATIONS

	Pancreas	*Papilla*	*Common Duct*	*Duodenum*	*Islet Cell*	*Total Pancr'y*	*Benign Lesions*
Columbia-Presbyterian 66-58 tumor 66-24 = 36.3	18	22	9	7	2	7	8
	10/46-10/50 24-2 = 8.3% mortality						
Lahey Clinic 90-79 tumor 79-10 = 12 6	42	26	4	7			11
	In last 41 cases, 3 deaths = 7.3%						
Mayo Clinic 48-10 = 26.8	27	17		3	1	1	
Memorial Hospital 44-14 = 31.8	34	2	1	7		4	
NYH-Cornell 24-7 = 31.8	13	6		4	1		

Total Radical: 272 PO Deaths: 65 (24%)

Five Year Survivals: 15 (pancreas, 3; papilla, 9; duodenum, 2; islet cell, 1)

There have been many more of these radical procedures done by surgeons in America and abroad which have not been reported, and the radical operation is now recognized as justified if the pancreaticoduodenal tumors are diagnosed

bladder was admitted to the service of Doctor William Barclay Parsons. We decided to do this operation in two stages with a cholecystgastrostomy at the first stage. Two weeks later, I assisted Doctor Parsons in the second stage which consisted of a resection of a segment of the duodenum with the carcinoma of the ampulla of Vater and a wedge-shaped portion of the head of the pancreas. This was by an end-to-end duodenorrhaphy and ligation of the resected common duct and the pancreatic duct. Silk technic was used throughout. Three months later, a stricture of the duodenum required a gastrojejunostomy. The patient did well, gained weight, was free of jaundice, and showed normal fat digestion on a measured fat intake and output test. But nine months after the resection of the pancreatic head and ampulla, the patient was readmitted with chills, steeple type temperature, recurrent jaundice, and a *B. coli* septicemia, and died of a *B. coli* cholangitis. Autopsy showed the stoma of the cholecystgastrostomy had markedly contracted, resulting in inadequate bile drainage and an ascending colon bacillus infection of the biliary tract. The liver did not show fatty infiltration, nor were there any evidences of residual or recurrent cancer.

Dragstedt, in 1918, and Mann and Kawamura, in 1922, demonstrated that the duodenum could be safely removed in experimental animals, and we had shown that the pancreatic duct could be occluded without compromising the patient's nutrition or causing fatty infiltration of the liver. In February 1935, the writer performed a two stage operation for carcinoma of the ampulla, doing a cholecystogastrostomy and a gastrojejunostomy in the first stage. After the jaundice was relieved, the entire duodenum, with a large part of the head of the pancreas, was removed, occluding the lower end of the common duct and the stump of the resected pancreas. The patient made a good convalescence and remained well for 20 months, but at the end of 25 months died with evidences of liver metastases.

During the next five years, we abandoned the cholecystogastrostomy as a bile-shunting procedure, using the cholecystojejunostomy because of the less frequent ascending cholangitis. But because of the necessity of a two stage procedure to relieve jaundice, and the necessary ligation of the resected common duct at the second stage, we encountered a serious postoperative complication in a biliary fistula due to the cutting through of the common duct ligature. Orator naïvely reported a case with this complication in 1936 in a two stage procedure. He stated that in doing a dressing following the second stage, after the patient had developed a biliary fistula, he removed an ascaris worm from the fistulous tract "wearing the common duct ligature as a necktie."

The two stage procedures were often associated with difficulties during the second stage, because of the extensive vascular adhesions which had developed in the right upper quadrant after the first stage. By 1940, the use of vitamin K to restore the blood clotting mechanism in the presence of obstructive jaundice had become well established, and the use of blood transfusion to prevent shock in extensive abdominal operations was well recognized. In March 1940, the writer performed the first one stage radical operation with removal of the entire duodenum and all of the head of the pancreas, with a choledochojejunostomy and occlusion of the resected pancreas, and demonstrated the advantages of the one stage procedure. Trimble of Baltimore reported a one stage procedure, carried out independently, on a patient several weeks later.

During the period of 1935-1945, a number of surgeons reported their modifications of the two stage procedure, notably Orr, Hunt, Cooper, and Illingworth. In 1937, Nemenyi reported a one stage procedure similar to the technic employed by Kausch in two stages, but neither of these surgeons did a total duodenectomy. In 1940, Hunt and Mahoney carried out one stage radical procedures. Brunschwig, in 1937, was the first to perform successfully a radical pancreaticoduodenectomy for carcinoma of the head of the pancreas, and since then he has been one of the most daring and able protagonists of the radical surgery of the pancreas. His textbook on this subject is very comprehensive.

At the 52nd annual meeting of the Western Surgical Association in 1944, Orr presented a comprehensive review of the cases of pancreaticoduodenectomy for carcinoma of the ampullary area, including 9 of his own cases. He gave 50 references in his bibliography. In this paper he discussed the diagnosis at operation, the justification for the radical procedures, the advisability of anastomosing the cut end of the pancreas to the jejunum, the choice of the one or two stage procedure, and the choice of the several technics reported up to that time. At the same meeting, Cole and Reynolds discussed the radical operation and presented the technic of a modified one stage procedure with a review of their 5 cases.

Since then, there have been many modifications (Pearse) in the technic of the two stage and one stage radical procedures, with comprehensive reviews of fairly large series from a number of leading surgical clinics, notably reports from the Mayo Clinic by Waugh, from the Lahey Clinic by Cattell, from the Memorial Hospital by Brunschwig, from the Cornell-New York Clinic by Child, and from the Columbia-Presbyterian Clinic (Frantz). A summary of the 243 cases from these five clinics is given in Table I.

TABLE I

SUMMARY OF RADICAL PANCREAS OPERATIONS

	Pancreas	*Papilla*	*Common Duct*	*Duodenum*	*Islet Cell*	*Total Pancr'y*	*Benign Lesions*
Columbia-Presbyterian 66-58 tumor 66-24 = 36.3	18	22	9	7	2	7	8
	10/46-10/50 24-2 = 8.3% mortality						
Lahey Clinic 90-79 tumor 79-10 = 12.6	42	26	4	7			11
	In last 41 cases, 3 deaths = 7.3%						
Mayo Clinic 48-10 = 26.8	27	17		3	1	1	
Memorial Hospital 44-14 = 31.8	34	2	1	7		4	
NYH-Cornell 24-7 = 31.8	13	6		4	1		

Total Radical: 272 PO Deaths: 65 (24%)

Five Year Survivals: 15 (pancreas, 3; papilla, 9; duodenum, 2; islet cell, 1)

There have been many more of these radical procedures done by surgeons in America and abroad which have not been reported, and the radical operation is now recognized as justified if the pancreaticoduodenal tumors are diagnosed

bladder was admitted to the service of Doctor William Barclay Parsons. We decided to do this operation in two stages with a cholecystgastrostomy at the first stage. Two weeks later, I assisted Doctor Parsons in the second stage which consisted of a resection of a segment of the duodenum with the carcinoma of the ampulla of Vater and a wedge-shaped portion of the head of the pancreas. This was by an end-to-end duodenorrhaphy and ligation of the resected common duct and the pancreatic duct. Silk technic was used throughout. Three months later, a stricture of the duodenum required a gastrojejunostomy. The patient did well, gained weight, was free of jaundice, and showed normal fat digestion on a measured fat intake and output test. But nine months after the resection of the pancreatic head and ampulla, the patient was readmitted with chills, steeple type temperature, recurrent jaundice, and a *B. coli* septicemia, and died of a *B. coli* cholangitis. Autopsy showed the stoma of the cholecystgastrostomy had markedly contracted, resulting in inadequate bile drainage and an ascending colon bacillus infection of the biliary tract. The liver did not show fatty infiltration, nor were there any evidences of residual or recurrent cancer.

Dragstedt, in 1918, and Mann and Kawamura, in 1922, demonstrated that the duodenum could be safely removed in experimental animals, and we had shown that the pancreatic duct could be occluded without compromising the patient's nutrition or causing fatty infiltration of the liver. In February 1935, the writer performed a two stage operation for carcinoma of the ampulla, doing a cholecystogastrostomy and a gastrojejunostomy in the first stage. After the jaundice was relieved, the entire duodenum, with a large part of the head of the pancreas, was removed, occluding the lower end of the common duct and the stump of the resected pancreas. The patient made a good convalescence and remained well for 20 months, but at the end of 25 months died with evidences of liver metastases.

During the next five years, we abandoned the cholecystogastrostomy as a bile-shunting procedure, using the cholecystojejunostomy because of the less frequent ascending cholangitis. But because of the necessity of a two stage procedure to relieve jaundice, and the necessary ligation of the resected common duct at the second stage, we encountered a serious postoperative complication in a biliary fistula due to the cutting through of the common duct ligature. Orator naïvely reported a case with this complication in 1936 in a two stage procedure. He stated that in doing a dressing following the second stage, after the patient had developed a biliary fistula, he removed an ascaris worm from the fistulous tract "wearing the common duct ligature as a necktie."

The two stage procedures were often associated with difficulties during the second stage, because of the extensive vascular adhesions which had developed in the right upper quadrant after the first stage. By 1940, the use of vitamin K to restore the blood clotting mechanism in the presence of obstructive jaundice had become well established, and the use of blood transfusion to prevent shock in extensive abdominal operations was well recognized. In March 1940, the writer performed the first one stage radical operation with removal of the entire duodenum and all of the head of the pancreas, with a choledochojejunostomy and occlusion of the resected pancreas, and demonstrated the advantages of the one stage procedure. Trimble of Baltimore reported a one stage procedure, carried out independently, on a patient several weeks later.

CARCINOMA OF THE PANCREAS

This type of pancreaticoduodenal tumor is the most treacherous and gives the poorest prognosis with any radical operative procedure. The reasons for this are: (1) Jaundice may not appear, and usually does not if the growth is in the body or tail of the organ. If it is in the head, jaundice will appear late, the farther the growth is from the common duct. (2) Severe pain is usually a prominent symptom, one that is too easily confused with that seen in gastroduodenal and biliary tract lesions. (3) These growths are not as a rule detectable by roentgen studies. (4) The tumors are usually of the infiltrating, invasive type of carcinoma, spreading early to the lymphatic drainage tracts and lymph nodes. (5) Rapid loss of weight and strength are characteristic and indicative of the systemic debilitating effect of these cancers. (6) In carrying out a pancreaticoduodenal resection of the head or body of the pancreas, the sectioning of the pancreas results inevitably in spillage of retained pancreatic juices. These have been demonstrated to contain cancer cells. The spillage results in local spread of cancer cells, and accounts for the too frequent local recurrences following the usual pancreaticoduodenectomy, and the conviction on the part of many surgeons that the radical operation for cancer of the pancreas is seldom more than a palliative procedure. Total pancreatectomy with duodenectomy has been advocated by Cattell and Cole if these lesions are to be treated surgically.

THE DIFFERENTIAL DIAGNOSIS OF PANCREATICODUODENAL TUMORS

The favorable prognosis in patients with these tumors, once they have recovered from the radical procedures, is dependent on early diagnosis and early operation. For this reason, these patients, especially those with jaundice, must not be studied to death. There are two essential diagnostic procedures which must be carried out in making a differential diagnosis.

(1) If the patient is jaundiced, and the majority of them are, it must first be determined whether the jaundice is obstructive in type rather than hepatic. In obstructive jaundice, the alkaline serum phosphatase level is always definitely elevated, whereas it is normal in jaundice of hepatic origin. On the other hand, the cephaline flocculation test and thymol turbidity test are usually markedly positive, with 4 plus readings in the cases of acute hepatitis with jaundice, whereas in obstructive jaundice, whether due to tumor or common duct calculus, these tests are negative.

(2) Once the diagnosis of obstructive jaundice is established, and in the patients with severe epigastric pain radiating to the back and with no demonstrable lesion by roentgen studies, the presence of a pancreaticoduodenal tumor should be suspected and the diagnosis kept in the foreground until ruled out. The essential test in this differential diagnosis is the study of duodenal contents by means of the double tube technic, as first proposed by Lägerlof and more recently emphasized by Bauman. It is hard to understand why this test is not more generally used by the internists who first see these patients.

early and found to be localized. There are certain reasons however which make the prognosis better in the ampullary growths than in the pancreatic cancers. These will be discussed under the separate headings of the sites of the tumors. Following this discussion, the analysis of the several procedures will be given and certain essential factors in carrying out any of the modifications will be emphasized, and the technic of the operation by the writer which has given him the best results will be presented.

CARCINOMA OF THE AMPULLA OF VATER

This tumor gives the best prognosis with radical pancreaticoduodenectomy for the following reasons. (1) It causes early biliary obstruction, giving promptly the cardinal symptom of progressive painless jaundice with a distended gallbladder. (2) The growth is usually of the papillary type of carcinoma remaining localized for a longer period than the other infiltrating pancreaticoduodenal tumors. (3) It is more apt to cause bleeding and sloughing of tumor cells which can be detected more readily by duodenal intubation and aspiration for cytologic examination (4) Careful roentgenographic studies with filling defects are detected at an earlier stage than in the other sites.

Painless jaundice is more frequently seen in these ampullary growths, which differentiates them from the pancreatic and common duct stones. It must be emphasized however that when sloughing of the papillary growth takes place, as it does in some cases, the jaundice will be temporarily relieved, simulating in this way the intermittent jaundice of ball valve common duct stone.

CARCINOMA OF THE DUODENUM

When this growth occurs near or in contact with the ampulla of Vater, it is difficult to differentiate it, both at operation and on pathologic section, from an ampullary cancer. If this occurs the duodenal tumor may cause early jaundice. However, the symptomatology is as a rule obscure and these tumors are not easily detected in the early stages by barium meal roentgen studies. Too frequently the tumors are diagnosed late and are irremovable at the time of the exploratory procedure. Here again, duodenal intubation and aspiration done in early suspected cases will show blood and tumor cells in the Papanicolaou smears.

CARCINOMA OF THE COMMON DUCT

The symptom of progressively deepening jaundice with a dilated, uninflamed gallbladder is characteristic. If the growth is above the pancreas, the lesion is usually painless. However, in the lower end of the duct it is usually indistinguishable from a carcinoma of the head of the pancreas, and may be associated with pain. The common duct carcinomas are usually of the infiltrating, stenosing type with less bleeding and sloughing of tumor cells. The level of the site of the tumor will determine the information to be obtained by duodenal aspiration studies, to be mentioned under the heading of Duodenal Intubation Test.

presence of pancreatic ferments, red cells, and cancer cells indicate a carcinoma of the common duct above the ampulla. If both bile and pancreatic ferments are absent, with the presence of blood and tumor cells, the growth may be in the ampulla, the lower end of the common duct, or the head of the pancreas, involving the ducts.

Cancer of the Pancreas. The duodenal findings depend on the part of the pancreas involved. If the growth is in the tail or body, bile may be present in normal amounts with jaundice absent. Usually there will be diminished ferments and blood and cancer cells would point to the growth in an area away from the common duct. The nearer the growth to the ampulla, the more difficult will be the differentiation from ampullary lesions.

Common Duct Calculus. The presence of cholesterol crystals and/or bile pigment particles and the absence or diminished amounts of bile, the presence of pancreatic ferments, and the absence of blood and cancer cells establish the diagnosis of common duct calculus.

It must be emphasized that the previously mentioned liver function tests and these duodenal content studies must be carefully correlated with the symptoms of pain, its character and radiation, or absence of pain; the story of loss of weight and strength; the presence or absence of a distended palpable gallbladder, and the presence or absence of barium roentgenographic findings in making a differential diagnosis. It cannot be too emphatically stated that to waste days and weeks in repeated unnecessary liver function tests on a patient more than 40 years of age and in watchful waiting, in the hope that the jaundice will clear and the symptoms abate, is consigning the patient to a hopeless prognosis if a cancer is present. But the most important decision to be made by the clinician without delay, if the studies do not establish the differential diagnosis, is to advise an exploratory operation by a surgeon experienced in upper abdominal surgery and familiar with the lesions under discussion, to ensure the earliest possible removal of such cancers.

During the past 10 years, there have been modifications in the technic of the two and one stage procedures, having to do with loop or Roux Y anastomoses of the common duct, the pancreatic duct, or the stump of the resected pancreas, and the gastrojejunostomy. From our own experience with several of these modifications, we have come to certain conclusions as to the principles to be followed in doing one or the other of the modified radical pancreaticoduodenectomies. These are recorded under separate headings with a discussion of the reasons for the conclusions, as well as certain safety factors in the preoperative, operative, and postoperative phases of the operation.

(1) We advocate the one stage procedure for the following reasons: (a) If the patient is cachectic and deeply jaundiced with severe liver damage, the probabilities are that the lesion is too far advanced to warrant a radical resection and, with an exploratory operation, a palliative bile-shunting procedure between the jejunum and the gallbladder is the most that can be done. This, together with the anastomosis of the dilated pancreatic duct to the jejunum, as advocated by Cattell, is warranted because of the relief from the intolerable pruritus which accompanies obstructive jaundice and the temporary improvement in digestion.

THE DUODENAL INTUBATION TEST

"A Miller-Abbott type of rubber tube 4 feet long and 16 french, divided into two longitudinal compartments by a central partition, is used. The duodenal end is provided with a perforated metal tip. The gastric canal is perforated where it is in contact with the stomach wall; it has no connection with the duodenum. The tube is passed through the nose into the stomach. This is best done the night before but may be inserted in the fasting state on the morning of the test. The patient rests on the right side, and the tube is manipulated into the duodenum under the fluoroscope by the roentgenologist. This may be difficult, time-consuming, or impossible. Pylorospasm, adhesions about the duodenum, or abnormal or unusual conformation of the stomach or duodenum may be the cause of failure. In several instances, 0.015 gm. of morphine hypodermically has enabled the passage of the tube into the duodenum. After the tube is in the duodenum, it is taped to the nose with adhesive plaster, and 10 cc. of a 25 per cent emulsion of finely powdered calcium carbonate in gum acacia solution is syringed into the stomach to neutralize excess acid. This must be repeated if the pancreatic juice fractions continue to be acid. The oral ends are joined to the receiving test tubes into which the juices are aspirated by constant gentle suction by means of a Wangensteen apparatus. The duodenal glass receiving tube must be iced to avoid destruction of ferments during collection. After obtaining the first 10 minute sample, 0.010 cc. of mecholyl chloride is injected subcutaneously. Ten, 20, and 30 minutes later, three further 10 minute fractions are collected. The fractions are preserved in ice until analyzed. The *p*H is determined with a Hellige *p*H meter. If the specimen is neutral or alkaline, its volume, amylase, protease, and lipase concentrations are determined.

"It is suggested that a solution of atropine sulfate for hypodermic injection be at hand to anticipate undue sensitivity to the vagomimetic drug. Especial care in asthma and heart disease is advisable. However, we have had very little trouble in this respect in over 500 cases" (Bauman).

Duodenal contents obtained by this technic give the following significant findings:

(1) The presence, decrease, or absence of bile.
(2) The presence of normal, decreased, or absent pancreatic ferments.
(3) The presence or absence of cholesterol crystals and bile pigment particles.
(4) The presence or absence of red blood cells.
(5) The presence or absence of tumor cells studied by the Papanicolaou technic.

With the data so obtained, the following differential diagnosis can be made:

Cancer of the Ampulla of Vater. Both bile and pancreatic ferments are decreased or absent. The presence of red blood cells and the finding of cancer cells with the Papanicolaou technic establish the diagnosis.

Cancer of the Duodenum. If the ampulla is not involved, both bile and pancreatic ferments will be present. Blood and cancer cells with bile and pancreatic ferments present in normal amounts point to a duodenal carcinoma.

Cancer of the Common Duct. Absence or diminished amounts of bile, the

any of the dogs. Pancreatic duct epithelium appeared to unite rapidly with jejunal mucosa as early as the 30th hour, and in some instances overgrew the jejunal mucosa.

(6) There are certain variations in the shape and size of the head of the pancreas, especially in relation to the superior mesenteric vessels and portal vein, which largely determine the difficulty and hazard of the radical operation. This applies especially to that portion which is spoken of as the lingula or uncinate process of the head of the pancreas. This may be absent or it may be so developed as to encircle the superior mesenteric vessels and lower end of the portal vein. When the duodenum and pancreatic head are mobilized, the uncinate process is not necessarily visible or palpable, and often is not identified until the head of the pancreas is sectioned from the neck. If this process is involved in the carcinoma, it may be impossible to separate it and the head from the vessels involved. Experiments are in progress to determine the feasibility of bridging the resected vein and artery by means of vascular grafts or fluid-repellent plastic tubes (Daniel). As yet, no successes have been reported in clinical cases, but have been successful in dogs.

(7) In some cases with the tumor in the body or tail, or where the growth is extensive and apparently limited to the pancreas, a total pancreatectomy has to be considered. If this is to be done, the spleen as well as the duodenum should be resected en bloc. The common duct should be anastomosed to the resected limb of the jejunum, followed by the gastrojejunostomy as in the usual pancreaticoduodenectomy. Of course the pancreatic duct would be removed with the pancreas and duodenum.

(8) Because of the possibility of leakage from one of the three stomas during the first week after the radical procedures, it is essential to establish adequate drainage of the denuded retroduodenal and subhepatic areas. This is best accomplished by sump drainage, using a larger soft rubber tube with side openings containing a smaller rubber tube to which continuous suction can be applied at the close of the operation. This has two more advantages: it prevents the soaking of the dressings with exudate that may have irritating and digestive action on the patient's skin; it makes it possible to measure the loss of fluid and electrolyte which may be serious, for in some instances of bile or pancreatic leakage 1 to 2 liters may be lost daily in the first postoperative week.

(9) Nonabsorbable suture and ligature material in fine grades should be used throughout; either fine silk or fine cotton gives equally good results. The use of catgut in any form invites disaster and accounts for many of the failures in the earlier attempts of radical surgery. Halsted's teachings in this respect are never better demonstrated than in these pancreaticoduodenal lessons. For the closure of the abdominal incision stainless steel, silver, or tantalum wire for through-and-through figure-of-eight or near-far-far-near sutures causes less reaction for a period of 12 to 14 days, and is good insurance against wound disruption in this operation.

(b) The danger of hemorrhage and postoperative oozing is controlled by preoperative vitamin K therapy. This is most effectively given in the form of hiquinone in doses of 1 gm. every 12 hours for two days before operation. If any anemia is present, blood transfusion will help to control bleeding as well as relieve the anemia. These two measures will restore the blood clotting mechanism unless the liver is so damaged as to derange the prothrombin level. For this reason, the prothrombin time should be determined before operation. If this level cannot be restored, the risk to the patient of a radical procedure is prohibitive. (c) The danger of two anesthesias and two operations is avoided. (d) The difficulties of extensive and, in some cases, massive vascular adhesions at the second and more difficult stage are avoided.

(2) The gallbladder should *not* be used in the *one* stage procedure to re-establish the flow of bile into the digestive tract. Cholecystogastrostomy is the worst form of shunt, for it is especially prone to ascending biliary infection because of gastric contents and particulate matter forced into the gallbladder and retained there by the strong gastric contractions and the tendency for this stoma to become narrowed as a result of the inequality between thick gastric and thin gallbladder walls.

(3) The common duct, dilated as it usually is in these lesions, when anastomosed to the jejunum, either end-to-side of duct to a loop of jejunum, or preferably, end-to-end of severed duct to the vertical limb of the resected jejunum (30 to 40 cm. in length), is seldom followed by a cholangitis. This is explained by the fact that there is a free flow of bile, the vertical jejunal limb has a peristalsis away from the duct, and the stoma shows little tendency to stenose as compared to a cholecystogastrostomy. In the two stage procedure, the gallbladder has to be used for the shunt. At the second stage, too often this is left undisturbed and the severed common duct is ligated. In too many cases the ligature has cut through the common duct, resulting in a most serious complication of a postoperative biliary fistula, a fistula difficult to close by any subsequent operation.

(4) Total duodenectomy should be an essential part of pancreaticoduodenectomy for two reasons, in either a partial or total pancreatectomy. First, because complete removal of the head of the pancreas so compromises the blood supply of the duodenum as to favor gangrene and fistula formation. Secondly, in the presence of malignancy in that area, lymphatics and lymph nodes, harboring tumor cells, cannot be as radically removed unless the duodenum is excised en bloc with the head of the pancreas.

(5) Implanting of the pancreatic duct into the jejunal loop is advisable for the following reasons: (a) The flow of pancreatic juice is restored, improving digestion. (b) The chances of a pancreatic fistula are much less than when the duct is occluded by a ligature, which often cuts through the duct wall. (c) It eliminates the uncertainty and argument regarding an occluded pancreas and its relation to fatty changes in the liver. These have been observed in dogs, but have not been corroborated in the human. (d) Pancreatic duct epithelium is avid in its rapid fusion with jejunal mucosa. Experiments in 20 dogs by John Hawk and the writer demonstrated that a simple approximation of the duct with two fine silk sutures to an opening in the jejunal mucosa of equal size resulted in a secure anastomosis in all the 19 surviving animals. Pancreatic fistula did not occur in

through both recti and into the oblique muscles is essential. The vertical left rectus incision is mentioned only to condemn it as inadequate and handicapping.

First Step. A careful review of the pancreas, duodenum, gastrohepatic omentum, and liver is done to determine the presence of metastasis.

Second Step. Incision of the peritoneum is made to the right of the duodenum to mobilize it and the head of the pancreas.

Third Step. A study of the head of the pancreas at the site of the emergence of the superior mesenteric vessels from behind the pancreas is done to determine the presence of a lingula or uncinate process, and the extent of its encirclement of the mesenteric vessels. This is further facilitated by dividing the ligament of Treitz and drawing up the first foot or more of the jejunum. Great care should be used to avoid injuring the superior mesenteric vessels. At the same time the inferior pancreaticoduodenal vessels can be ligated and divided.

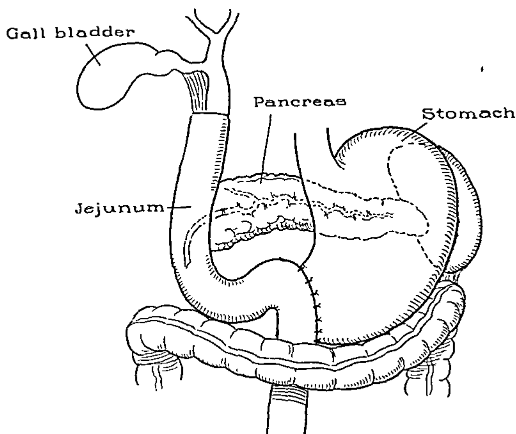


FIG. 1.—Postcolic procedure.

Fourth Step. The common duct is separated from the portal vein in the gastrohepatic or hepatoduodenal ligament, below the cystic duct and well above the carcinoma, and is divided between clamps. The gastroduodenal artery distal to the hepatic artery is usually seen and should be divided between ligatures. This controls much of the blood supply to the duodenum.

Fifth Step. The stomach is divided proximal to the pylorus between Payr clamps.

Sixth Step. The pancreas is now divided anteriorly at the junction of head and body, and the splenic vessels and portal vein are identified. The portal vein and

PREOPERATIVE CARE

Measures to determine and treat cardiovascular, pulmonary, renal, and hepatic dysfunction are essential before undertaking radical pancreaticoduodenectomy. Preoperative determinations of chloride, sodium, and particularly potassium, as well as blood volume studies are important as baselines for later imbalances.

Jaundice in many of these patients is unfortunately of many weeks' duration. Serum bilirubin determinations give the most accurate information on the degree of biliary obstruction and jaundice. Prolonged prothrombin and clotting time demands intensive preoperative vitamin K therapy. Failure of prothrombin time to respond to this treatment indicates severe liver damage and makes operation inadvisable. Blood urea nitrogen studies and residual urine determinations in prostatic hypertrophy are necessary. Myocardial damage should be checked with electrocardiograms to determine cardiac reserve and the need for digitalis therapy.

It is advisable to give penicillin 50,000 units every four hours for 24 hours before operation to prevent gram-positive coccus infection. A preoperative blood transfusion is usually indicated from the blood studies. A Levin tube placed in the stomach before operation ensures against gastric retention, vomiting, and strain on the gastrojejunostomy stoma.

ANESTHESIA

The preoperative studies of the patient should be carefully considered in deciding the type of anesthesia to be used. An experienced and skillful anesthetist should give the anesthesia that he and the surgeon have chosen after considering the patient's studies. The radical operations are three to four hour procedures and require adequate relaxation in going in and coming out without compromising the blood pressure and pulse rate. Local infiltration of the peritoneum about the abdominal incision, or careful use of curare as an adjuvant to the general anesthesia helps in the first and last parts of the operation.

THE OPERATIVE PROCEDURE

For a review of the many modifications of the technic of pancreaticoduodenectomy, the reader is referred to Child's monograph. Because the writer has tried a number of his own and others' modifications and has arrived at the procedure which has given him the best approach and results, the one stage operation as used in his later cases is described in detail and illustrated. Figure 3 represents the best procedure in his opinion.

Incisions

The incision (Fig. 4) depends on the type of operation to be done. For the resection of the duodenum and head of the pancreas, a vertical right rectus splitting incision from the costal margin to the umbilicus level gives adequate and optimal exposure. For resections of the entire pancreas and duodenum, and for exploring for islet cell tumors, a curved transverse incision above the umbilicus

of the pancreatic stump are then approximated to the jejunum, around the duct anastomosis, by means of interrupted silk sutures.

Tenth Step. The cut end of the jejunum is now anastomosed end-to-end with the common duct. If the lumen of the jejunum is much longer than the common duct, a portion of the mesenteric border can be closed, leaving the remainder of the lumen to be sutured to the common duct. The anastomosis can be reinforced by tacking the hepatoduodenal ligament or the gallbladder to the jejunum, to remove any tension from the choledochojejunostomy.

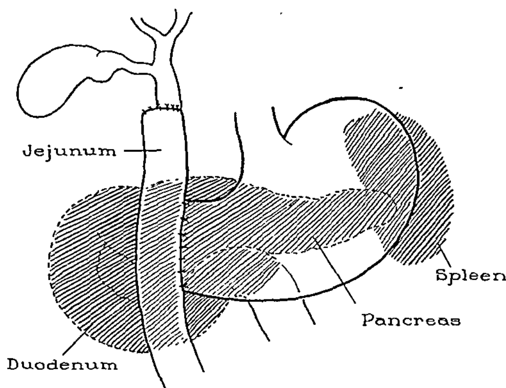


FIG. 3.—Total pancreatectomy.

Eleventh Step. The rent in the mesocolon should be carefully closed around the vertical limb of the jejunum below the gastrojejunostomy.

Twelfth Step. Peritoneal toilet, sponge and pad count, and careful review of the hemostasis and anastomoses.

Thirteenth Step. A soft rubber tube, perforated laterally, with a smaller tube inside it, as a sump drain, is now placed in the subhepatic space away from the anastomotic areas.

Fourteenth Step. Near-far-far-near stainless steel or tantalum wire sutures through all layers of the abdominal wall, with interrupted fine silk mattress sutures for the peritoneum and posterior rectus sheath are placed and tied, before the wire sutures are tied or twisted to approximate the edges of the incision (Fig. 4.) These wire sutures should be left in place 12 to 14 days. The long loop of each wire should be cut at each end near the skin. The next day the twisted wire ends will come away easily.

the superior mesenteric vessels are carefully dissected away from the head of the pancreas. This is especially important and often difficult if the uncinate process encircles these vessels. The head of the pancreas, the pylorus, the end of the common duct, the duodenum, and the first part of the jejunum can now be removed *en bloc* together with the adjacent lymph nodes.

Seventh Step. By dividing the jejunum below the ligament of Treitz, the distal end can be drawn up vertically for anastomoses with the stomach, pancreatic duct, and common duct as illustrated (Figs. 1 and 2), and eliminates the necessity of closing the distal end of the duodenum at the duodenojejunal junction and a jejunojejunostomy distal to the other anastomoses. A vertical segment of jejunum, at least 12 to 15 inches (30 to 38 cm.) long is then brought up retrocolically, through the rent in the mesocolon, for the anastomoses.

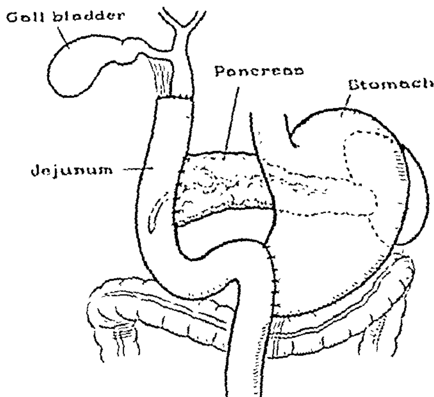


Fig. 2.—Antecolic procedure.

Eighth Step. At a distance of 12 inches from the distal divided end of the jejunum, an end-to-end gastrojejunostomy is carried out on the antemesenteric border of the jejunum.

Ninth Step. Proximal to the gastrojejunostomy, the divided end of the pancreatic duct is approximated to a punctured opening in the jejunum, on the antemesenteric border, by means of two fine silk sutures. Before these are tied a fine rubber or plastic tube, 5 cm. long, is inserted into the duct and passed into the jejunum. This acts as a temporary bridge, but is passed in 36 to 48 hours. The cut edges

is great danger of precipitating it by overhydrating the patient with saline infusions for this only dilutes the serum potassium and results in peripheral edema and edema ileus. By carefully maintaining these fluid and electrolyte balances, Doctors Lockwood, Parsons, and Randall were able to reduce the previous postoperative mortality at the Columbia-Presbyterian Clinic from 36 per cent to 8.3 per cent during the past four years. Similar striking improvements have been noted in the radical pelvic operations by Brunschwig at the Memorial Hospital, as reported by Eliel and Pearson and by McInnes et al.

Because of suction drainage and the severe operative procedure, ambulation as early as 24 to 48 hours as in other abdominal operations is not advisable, although having the patients stand each day and walk about the bed is wise. They should not sit in chairs with pressure on the popliteal areas.

RESULTS

The operative risk of radical surgery for cancer of the pancreaticoduodenal area, with a better understanding of the evaluation of the patient's condition, a better understanding of the safety factors and the measures to prevent the complications by the use of the ancillary services, as well as improved technics of the operation, has been markedly lowered. This is as true in this area as it is true of many other radical procedures during the past 10 years, such as pneumonectomy, esophagectomy, total gastrectomy, hemipelvectomy, and pelvic exenteration.

But it must be acknowledged and recognized that much of the radical surgery for cancer is palliative in the various fields in which it is used. Palliation is justified if it prolongs life and relieves pain, without leaving the patient with serious irremediable dysfunction and intolerable physical and mental distress. Strong and Pollock in a recent survey of radical mastectomy for cancer, make the following cogent remark: "Limitations of the field of usefulness of any operation should not be considered failures of that operation. It is a grievous error to condemn a method of proved curability because it is not a panacea. Furthermore, the poor results obtained when radical mastectomy is not properly done are not necessarily failures of the operation; they may be failures of the operator."

Certainly there is a difference in the prognosis following the radical procedure for an ampullary growth, as compared to that of pancreatic cancer. The reasons for this have been given. The future hope for improvement in the prognosis following the radical surgery for these lesions lies in not studying these elderly patients, with cardinal symptoms of jaundice, of constant severe epigastric pain radiating to the back, for periods of weeks with watchful waiting, and, among the internists who first see these individuals, in recommending early operation if the diagnosis is not clear, or if the diagnosis is reasonably established, urging immediate surgery by a competent surgeon.

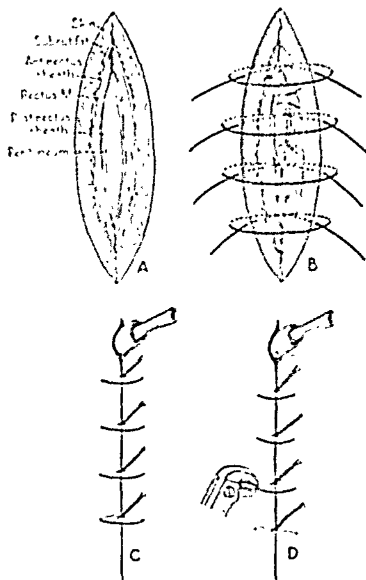


Fig. 4.—"Near-far, far-near" steel wire sutures through all layers for closure of abdominal incision.

POSTOPERATIVE CARE

Careful determinations of the patient's intake and output and daily determinations of blood CO_2, pH, and the serum sodium and potassium levels are mandatory, if serious electrolyte and fluid imbalances are to be avoided. The syndrome of metabolic alkalosis and potassium deficiency—asthenia, anorexia, low blood pressure, intestinal distention, and distortion or disappearance of normal T waves in the electrocardiogram—may appear from the fourth to the 10th postoperative day. This, if continued, results in death, but can be quickly remedied by the administration of potassium chloride, 1 gm., b.i.d. or t.i.d. Serum potassium determinations and electrocardiograms detect such a threatened syndrome. There

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MECHANISM OF GEIGER TUBES AND SCALERS

Radioactive iodine decays by the emission of both beta and gamma radiation. Beta particles are electrons of varying energy, which produce ionization in tissues by means of their negative charge. All of these particles are absorbed by about 3 millimeters of skin or other soft tissue. Gamma rays are uncharged quanta of



Fig. 1.—A portable survey meter used particularly in scanning patients for metastases. The G-M tube is shielded by 1 cm. of lead (Nucleonic Corp., Model RMI).

energy (photons) and are electromagnetic in nature. They cause ionization only through the production of secondary electrons, in being partially or wholly absorbed by materials through which they are passing. Certain of the gamma rays of I^{131} may traverse the thickness of the body without being absorbed. About $\frac{1}{10}$th inch of lead is required to stop half of these rays. Since the patient's skin will stop the beta particles emitted by the I^{131} trapped by the thyroid gland, all measurements of the body activity in situ, subsequent to tracer doses of I^{131}, are made with gamma ray detectors.

The bell-shaped Geiger-Müller tubes which have been employed until recently

Radioactive Iodine in the Diagnosis and Treatment of Thyroid Disease

GEORGE M. CURTIS, M.D. AND CHARLES V. MECKSTROTH, M.D.

PHYSICAL CHARACTERISTICS OF RADIOIODINE (I^{131})

THE USE OF RADIOACTIVE IODINE for the determination of thyroid activity, *in health* as well as in disease, is bringing about a more complete understanding of both normal and pathologic thyroid physiology than has been possible by the use of previous methods. Two main factors account for this progress: (1) The human body contains no I^{131} under normal circumstances, yet appears unable to distinguish between it and ordinary iodine, I^{127}; (2) much smaller quantities of I^{131} can be evaluated with a suitable detector such as a Geiger-Müller counter, than is possible with I^{127} using present-day microchemical technics. Studies with the aid of radioiodine may be carried out after the administration of small doses, known as *tracers* which produce little if any demonstrable effect on the thyroid gland or on other body organs. By the use of these tracers, the absorption, metabolism, and excretion of the element can be followed throughout the body and the relative rates of these processes evaluated.

There are at least 14 radioactive isotopes of iodine. The most generally used is I^{131}. Isotopes of an element may be defined as two or more chemical species (e.g., I^{127} and I^{131}) which have the same atomic number (53), the same nuclear charge (53 protons), the same number and arrangement of orbital electrons (53), but differ in atomic weight (127 and 131); or in the structure of the nucleus (74 neutrons for I^{127}, 78 neutrons for I^{131}). The radioactivity of I^{131} is manifested in the process whereby it "decays" to the stable state of the gas xenon (54^{Xe131}) as the result of the spontaneous omission of beta particles (electrons) and gamma rays (similar to x-rays of short wave length).

PREPARATION OF I^{131}

The first radioisotope of iodine I^{128} was isolated and described by Fermi in 1934 and was originally used in physiologic studies by Hertz et al. in 1938. This I^{128} was prepared in the cyclotron by the neutron bombardment of iodine, tellurium, or antimony. However, the short *half-life* of 25 minutes restricted biologic studies to a brief period. It was not until the preparation of I^{131}, with its half-life of eight days, that numerous studies could be readily carried out in the various fields of thyroid activity.

The I^{131} in use today is prepared in the uranium chain-reaction pile either (1) as one of the members of the mass 131 fission products of uranium 235 or (2) by the neutron bombardment of tellurium. The greater part of I^{131} is prepared dur-

ing the first of these reactions and is isolated by a complicated process of chemical separation from the other products of nuclear fission. The activity of the final solution when sent to the various laboratories is about 20 millicuries per milliliter.

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in tracer studies consist of cylinders with a center wire insulated from the silvered chamber walls. They are usually filled with an alcohol-argon gas mixture. Sufficient voltage is applied to the center wire to enable a current momentarily to bridge the gap between the center wire and the wall when an ionizing particle enters the sensitive gas-volume through the mica window. This will initiate an "avalanche" of ionization in the gas, under the influence of the high applied voltage, and will register as one pulse to the preamplifying tube.

The pulses from the G-M tube are fed into a suitable recording device, depending on the objective of the study at hand. For example, a portable rate meter (Fig. 1) can be used when larger doses are administered to patients with thyroid malignancy. For tracer studies with small doses, an automatic scaling circuit is employed.

The efficiency for gamma rays of the bell-shaped, mica window G-M tubes is less than 1 per cent and for this reason new tubes have been designed. Figure 2 illustrates a more sensitive lead-shielded bismuth plate tube with which thyroid uptake studies can be performed after the administration of from 5 to 10 microcuries of I^{131}. The recently developed scintillation tubes are expected to increase further the detection of minimal doses.

ADMINISTRATION OF I^{131}

The first radioisotopes of iodine were available in limited quantities and were given intravenously to make certain of complete absorption. This procedure necessitated undesirable radiation of the investigator and was soon abandoned in favor of the oral route when larger quantities became available.

The radioiodine is shipped in containers to the various laboratories where it is diluted as necessary and pipetted into glass vials. These vials are assayed quantitatively for activity, immediately before administration to the patient. This serves both as a base line for tracer studies and as a double check to prevent errors from possible mislabeling. This assay is carried out with the glass vial at a distance of 15 cm. from the lead-shielded G-M tube. Under this geometry, a 10 microcurie dose registers about 40 counts per second with the equipment shown in Fig. 2. The patient is then told that he is to receive a tracer dose of radioactive iodine which is handed to him by means of long steel forceps. The patient drinks the contents of the vial and several tap water rinses.

The administration of large therapeutic doses, on the order of 25 to 100 millicuries (1000 microcuries = 1 millicurie), presents a problem for the investigator. All patients receiving such amounts have taken previous tracer doses and are acquainted with the procedure. In these situations the lead carrier with the vial inside is placed on the patient's table. The administrator steps back 6 feet or more while the patient removes the lead lid from the carrier and drinks the contents of the vial, followed by tap water rinses.

Nevertheless, the greatest exposure to radioactivity is encountered by the person who administers the large therapeutic doses and later surveys the patient. The exposure of nursing personnel is usually insignificant, one exception being bedpan care of patients who have just received large therapeutic doses. Although such instances are seldom encountered, these bedfast patients are not considered

good candidates for intensive radioiodine treatment because of the dangers of transportation of their excreta in bedpans.

Workers who are exposed to any appreciable radioactivity must wear a film badge or some form of dosimeter in order to ascertain the amount of exposure they receive. Interval blood counts are also required in order to determine an incipient leukopenia or anemia. Bone marrow studies may be indicated as a more thorough periodic check.

Exposure to radioactivity can be held to a minimum, and within limits accepted as safe, by careful planning.

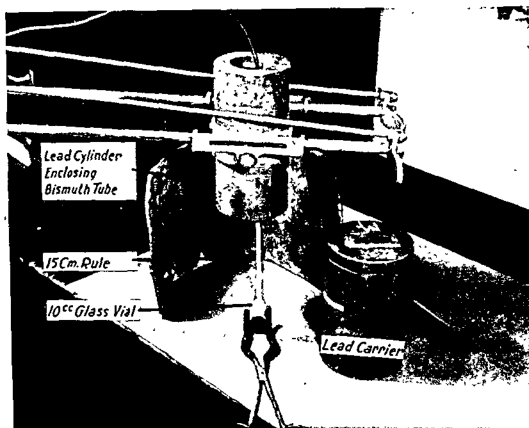


Fig. 2.–The bismuth-plate tube (Sylvania GG306), enclosed by a ¾ inch lead cylinder, is mounted on a portable x-ray stand. The recording instrument (Tracerlab Autoscaler) is not shown.

THYROID PHYSIOLOGY STUDIES WITH I^{131}

Many of the earlier studies of the physiology of the thyroid gland, using the radioiodine technic, were thought to be original in nature. However, it soon became apparent that various of these so-called "discoveries" were merely confirmation of work done many years previously, using the microchemical determination of I^{127}. No evidence has yet been presented that significant chemical or physiologic differences exist between I^{127} and I^{131}. The number and arrangement of orbital electrons are identical and apparently the body cells cannot differentiate between the stable and radioactive forms.

The possibility of simple exchange in the body between I^{131} and I^{127} has been considered. When radioiodine is mixed with an aqueous solution of iodate or diiodotyrosine, no exchange is observed. When radioiodine is added to homogenized thyroid tissue, no exchange takes place. However, when *surviving* thyroid slices are used, the radioiodine is incorporated into radioactive diiodotyrosine and thyroxine (Morton and Chaikoff). Thus, it appears that the thyroid cell must be *living* in order to convert inorganic radioiodine into the organic, protein-bound form.

FATE OF ORALLY ADMINISTERED I^{131}

In general, the iodide ion behaves in a manner similar to the chloride ion in its absorption from the gastro-intestinal tract. It soon passes through the liver and becomes dispersed throughout the entire body. The greater part of the iodine is then gradually picked up by the thyroid gland or excreted by the kidney. The rate and magnitude of thyroid uptake are commonly regarded as direct indications of the rate of thyroid activity. A number of clinics now administer tracer doses of I^{131} as part of their routine diagnostic work-up of all patients with thyroid disease.

Radioiodine enters into the inner metabolism of the thyroid cell and becomes incorporated into radioactive diiodotyrosine and thyroxine. In the form of these two amino acids, radioiodine leaves the thyroid gland to be distributed to the various body tissues and organs. The rate of appearance in the blood stream of this newly formed, protein-bound radioiodine has been used in certain clinics as a test of thyroid function. It necessitates, however, the use of large tracer doses.

A high percentage of the radioiodine which is not "trapped" by the thyroid gland is excreted by the kidney. The greater part of this excretion takes place within the first 24 hours. It thus becomes apparent that if the uptake by the thyroid gland is high, the amount excreted by the kidney is low, and vice versa. Quantitative assay of the thyroid and urine at the end of 24 hours will usually account for from 70 to 90 per cent of the amount administered, the remainder being scattered throughout the various body tissues, especially muscle and liver. Occasionally a patient will show a selective secretion of I^{131} by the stomach. This must be taken into consideration when scanning a patient for possible metastases.

MODE OF ACTION OF I^{131} IN THE THYROID GLAND

The metabolism of radioiodine in the thyroid gland may be divided into three phases: (1) As iodide, it must penetrate its membrane and enter the thyroid cell. (2) Iodine becomes incorporated into thyroxine and then diiodotyrosine by means of an intricate intracellular enzyme system. Diiodotyrrosine is generally regarded as the precursor of thyroxine, the thyroid hormone. This is then stored in the colloid of the alveolus as thyroglobulin, which includes thyroxine, diiodotyrrosine, and some inorganic iodine. (3) Thyroxine is released from the colloid on stimulation by the thyrotropic hormone of the anterior pituitary.

In the earliest studies it was thought that radioiodine was concentrated in greatest amounts in the cells of the alveolus rather than in the colloid (Hamilton et al.). This was demonstrated by placing microscopic sections of the radioactive

thyroid tissue on a sensitive photographic plate. An *autoradiograph* resulted. Owing to these findings it was originally reasoned that the therapeutic effects of I^{131} were brought about *during its passage* through the thyroid cell. However, when further series of autoradiographs were made and reported (Leblond et al.), it was shown that the passage of radioiodine through the thyroid cells was only transient, and that the therapeutic effects of the I^{131} were largely due to its *storage in the colloid* with consequent irradiation of the surrounding cells (Leblond et al.; Dobyns and Lennon).

Ionization in tissues produces a denaturation of proteins and the accumulation of a histamine-like substance. The denaturation process possibly results from the ionization of water to form the powerfully reactive free radicles, H^+ and OH^-. In turn, the destruction of a delicate intracellular enzyme system takes place and cell death ensues. The histamine-like substance, resulting from cell destruction, is believed to account for the systemic effects of irradiation on the circulatory, gastro-intestinal, and nervous systems. With regard to I^{131}, 95 per cent of the resultant histologic changes in the thyroid gland are caused by the beta particles, and 5 per cent are due to the gamma rays.

DIAGNOSIS OF THYROID DISEASE WITH I^{131} TRACER STUDIES

The clinical diagnosis of thyroid disease, and particularly of its functional changes, is at times difficult, especially when the issue is clouded by the occurrence of coexisting disease such as anxiety states, congestive heart failure, the leukemias, malingering, and neoplasms. For this reason, any laboratory method which will ascertain the state of thyroid activity is desirable. Radioactive iodine, in small tracer doses, is one of these methods and has been accepted as a suitable adjunct in the laboratory diagnosis of thyroid dysfunction.

The methods used in making these tracer studies vary among workers because of the expense involved, the availability of space and personnel, and the advances made in technical equipment. The method herein described is quite practical and enables the determinations to be carried out subsequent to doses of from 5 to 10 microcuries.

Uptake in the Thyroid Gland

A dilution mixture of I^{131} is prepared so that 10 microcuries are contained in 1 milliliter. Doses are pipetted into a 10 ml. glass vial which contains 5 ml. of a solution of NaOH (3.2 gm.) and $Na_2S_2O_3$ (1.9 gm.) diluted to a volume of 4 liters. This vial is then placed 15 cm. from the G-M tube and assayed for net counts per second after correction for background radiation. The arrangement in Fig. 2 gives values of about 40 counts per second (c/s) for 10 microcuries. The dose is then administered to the patient who also drinks the several tap water rinses.

After the desired time interval, the G-M tube is placed in line with the patient's thyroid gland, 15 cm. from the skin (Fig. 2) and net counts per second are then obtained. Two correction factors are necessary before the uptake can be determined. First, the decay factor of I^{131} must be considered. Second, a geometric

correction factor should be applied. The latter is necessary because of the difference in the geometry of the small glass vial and variously shaped thyroid glands. Figure 3 shows various shapes of the gland and the correction factors determined by the laboratory equipment described above.

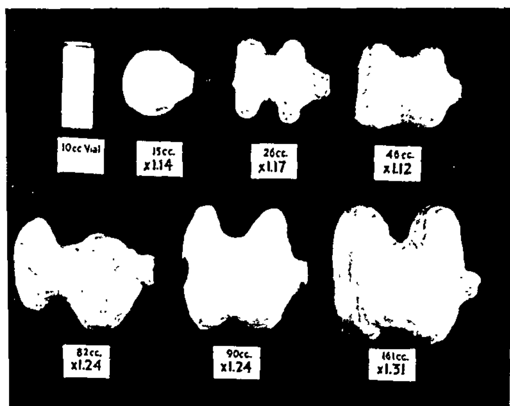


Fig. 3.—Geometric correction factors for glands of various sizes and shapes.

The following formula is then applied:

$$\frac{\text{c/s obtained over gland}}{\text{c/s administered}} \times \frac{1}{\text{decay factor}} \times \text{geometric correction factor} \times 100 = \text{per cent of uptake in the gland}$$

An example follows:

$$\frac{20.6}{40.2} \times \frac{1}{91.8} \times 1.12 \times 100 = 61.6 \text{ per cent}$$

The proper time for obtaining counts over the thyroid gland will depend on the patient under study. Usually, except in severe hyperthyroidism, a single count at 24 hours will suffice. In cases of severe hyperthyroidism, especially those of Graves' disease, multiple counts are desirable, and a graph of the uptake is charted. This is necessary because of the rapid turnover of I^{131} in the diffuse hyperplastic gland. As shown in Fig. 4, it is possible for a patient with severe hyperthyroidism to have a lower uptake than a patient with moderate hyper-

thyroidism if but a single 24 hour count is obtained. A practical solution is to *obtain counts at three, six, and 24 hours* if the differential diagnosis is doubtful.

In large series of studies the uptake by the thyroid gland of hypothyroid patients is normally below 10 per cent. Values for euthyroid patients will generally lie between 10 and 40 per cent. Hyperthyroidism should be suspected in patients with values above 40 per cent. These values are only relative and some overlap is to be expected.

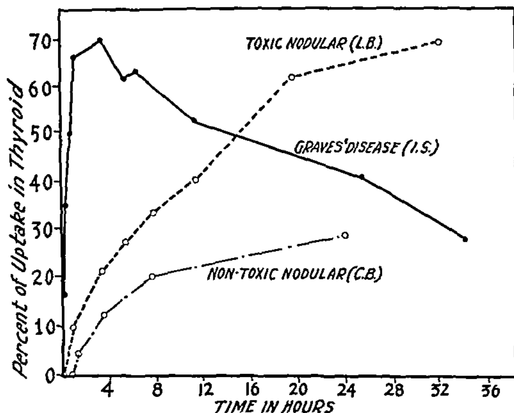


Fig. 4.—Typical I^{131} uptake curves for Graves' disease, toxic nodular, and nontoxic nodular goiters. The rapidity of uptake in Graves' disease necessitates multiple counts during the first few hours.

Urinary Excretion

The urine excreted after the administration of a tracer dose is collected and assayed quantitatively. Usually the first 24 hour excretion is sufficient; however, specimens obtained at longer or shorter time intervals may be used. The urine is passed directly into a 2 liter wide-mouthed glass jar. On assay, the jar is filled with water to within 2 cm. of the top, and thoroughly mixed. The G-M tube is *placed 2 cm. above this fluid level*, just above the lid, and net counts are obtained. The 2 cm. distance was determined by assaying a tracer dose at 15 cm., diluting it with 2 liters of water, and then ascertaining the distance of the tube from the water level at which counts representing 100 per cent of the tracer dose were obtained. The formula used for the determination of urinary excretion is similar to that of gland uptake, except that no geometric correction factor is involved.

A hypothyroid patient will usually excrete over 60 per cent of the tracer dose

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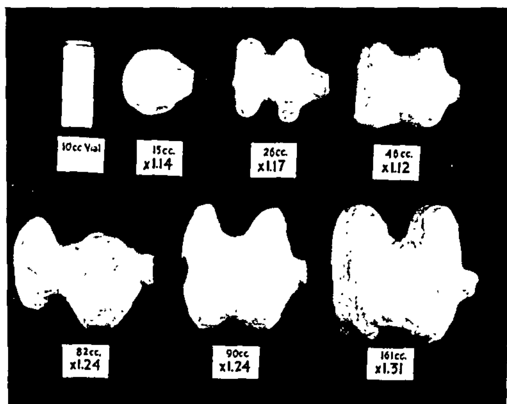


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TREATMENT OF THYROID DISEASE WITH RADIOIODINE

Hertz and Roberts, in the spring of 1941, were the first to use radioactive iodine for the treatment of Graves' disease. Since that time numerous reports have appeared regarding its success and failure, its advantages and disadvantages. The first indication for this new type of treatment was recurrent Graves' disease, with complications from previous surgery, namely damage to the laryngeal nerves and/or the parathyroid glands. The early results were promising. When more radioiodine became available, the indications for administration were expanded to include all types of Graves' disease and more recently toxic nodular goiter.

Graves' Disease

Diffuse hyperplastic goiter with hyperthyroidism has readily lent itself to radioactive iodine therapy owing to the high iodine uptake by this type of pathologic thyroid gland. In addition, the uptake is usually diffuse in its distribution as opposed to that of a toxic nodular goiter. Therefore, not only is the degree of overactivity diminished, but the enlarged gland is usually also decreased in size.

A complete evaluation of the patient from both the clinical and laboratory standpoints should precede the administration of I^{131}. The laboratory data should include a basal metabolic rate (BMR), somnolent metabolic rate (SMR), protein-bound serum iodine (PBI), and a radioiodine tracer uptake (RAI) study. The serum cholesterol may also be determined. A careful history should be obtained to rule out any possibility of previous iodine medication, since this would have an inhibitory effect on the uptake of radioiodine. The size of the gland is estimated, and the therapeutic dose then calculated. Approximately 0.1 millicurie is given per gram of thyroid. This amount is usually administered in two or more divided portions, allowing an interval of from two to four months between doses. The patient is followed to observe the clinical effects and at one to three month intervals the laboratory tests listed above are repeated. The RAI tracer study, however, cannot be repeated earlier than two months after the administration of a 5 millicurie dose unless less sensitive G-M tubes and larger amounts of I^{131} are used. The final amount of I^{131} given is frequently different from the original estimated requirement.

The generally accepted indications for using I^{131} in the treatment of Graves' disease are (1) recurrence after surgery has been performed, with or without injury to the parathyroids and/or recurrent laryngeal nerves; (2) refusal of surgery; (3) failure of propyl thiouracil treatment; (4) severe risk cases, such as those presenting cardiac damage with congestive failure, which cannot be controlled by antithyroid drugs and for which surgery is regarded as too hazardous.

The principal advantages of radioiodine in the treatment of Graves' disease lie in the avoidance of the complications of surgery. Nevertheless, frequently a satisfactory beneficial response to radioiodine is delayed because of inadequate dosage. This disadvantage can prove to be an important economic factor since most of these patients are in the wage-earning age group. With routine preoperative preparation, using iodine, calcium, phosphorus, and vitamin D, adequate

during the first 24 hours. Values for euthyroid patients range from 60 on down to 30 per cent, while hyperthyroid patients will generally excrete less than 30 per cent in this time interval. Obviously, *all* urine passed during the determined period must be saved if the test is to be of clinical value.

CORRELATION WITH OTHER DIAGNOSTIC PROCEDURES

The various tests ordinarily used for the determination of thyroid function have faults and limitations. The BMR is a measure of oxygen consumption, an indicator of the total body metabolism which is generally assumed to be largely governed by the activity of the thyroid gland. However, there are other diseases besides hyperthyroidism which elevate the BMR in a patient, such as leukemia, anxiety states, and congestive heart failure. The recently introduced SMR (*somnolent metabolic* rate) in which a BMR is performed during sleep produced by intravenous nembutal, is a recognized advance (Rapport, Curtis, and Simcox). This is chiefly of value in the differentiation of anxiety states, yet it still gives a false indication of actual thyroid function in other organic lesions such as congestive failure and neoplasms. The PBI (protein-bound blood iodine) is more valuable in the elimination of nonthyroidal hypermetabolism (Rapport and Curtis), but should not be used when the patient has recently received iodine in any form, either as therapy or in diagnostic studies. The cholesterol level commonly used as a test for thyroid function is obviously an indirect method.

Nor is the determination of the uptake of radioiodine by the thyroid gland a perfect test. In a fashion, it parallels the PBI in its limitations. If a patient has recently received iodine in any form, a marked diminution will be noted in the glandular uptake. At least one month, and preferably more, should elapse before tracer studies become valid on patients who have had Lugol's solution, cholecystography, intravenous pyelography, or lipiodolization, etc. Commonly used cough medicines and sedatives often contain significant amounts of iodine. Even the barium mixture used in gastro-intestinal fluoroscopy contains appreciable amounts.

Thiouracil preparations likewise depress the uptake of radioiodine but their action is comparatively short-lived. These compounds should be discontinued for at least one to four weeks before a valid uptake is obtainable. Treatment with desiccated thyroid should be stopped for at least four to six weeks before the uptake returns to a true value.

Nevertheless, the advantages of radioiodine tracer studies far outweigh their limitations and consequently these studies have become of value in the differential diagnosis of thyroid disease. Werner et al. have reported their correlation of the radioiodine uptake with other clinical tests of thyroid activity. Its use in establishing the diagnosis of hyperthyroidism is well grounded. However, it appears to be of equal or greater value in those patients with an elevated BMR, yet without thyroid disease. Anxiety states, malingering, hypertension, congestive failure, the leukemias, and neoplasms are but a few of the diseases which can be differentiated in this manner from hyperthyroidism. Obviously, because of its limitations, the radioiodine tracer study will serve to supplement other methods of diagnosis of thyroid disease, rather than replace them.

TREATMENT OF THYROID DISEASE WITH RADIOIODINE

Hertz and Roberts, in the spring of 1941, were the first to use radioactive iodine for the treatment of Graves' disease. Since that time numerous reports have appeared regarding its success and failure, its advantages and disadvantages. The first indication for this new type of treatment was recurrent Graves' disease, with complications from previous surgery, namely damage to the laryngeal nerves and/or the parathyroid glands. The early results were promising. When more radioiodine became available, the indications for administration were expanded to include all types of Graves' disease and more recently toxic nodular goiter.

Graves' Disease

Diffuse hyperplastic goiter with hyperthyroidism has readily lent itself to radioactive iodine therapy owing to the high iodine uptake by this type of pathologic thyroid gland. In addition, the uptake is usually diffuse in its distribution as opposed to that of a toxic nodular goiter. Therefore, not only is the degree of overactivity diminished, but the enlarged gland is usually also decreased in size.

A complete evaluation of the patient from both the clinical and laboratory standpoints should precede the administration of I^{131}. The laboratory data should include a basal metabolic rate (BMR), somnolent metabolic rate (SMR), protein-bound serum iodine (PBI), and a radioiodine tracer uptake (RAI) study. The serum cholesterol may also be determined. A careful history should be obtained to rule out any possibility of previous iodine medication, since this would have an inhibitory effect on the uptake of radioiodine. The size of the gland is estimated, and the therapeutic dose then calculated. Approximately 0.1 millicurie is given per gram of thyroid. This amount is usually administered in two or more divided portions, allowing an interval of from two to four months between doses. The patient is followed to observe the clinical effects and at one to three month intervals the laboratory tests listed above are repeated. The RAI tracer study, however, cannot be repeated earlier than two months after the administration of a 5 millicurie dose unless less sensitive G-M tubes and larger amounts of I^{131} are used. The final amount of I^{131} given is frequently different from the original estimated requirement.

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The principal advantages of radioiodine in the treatment of Graves' disease lie in the avoidance of the complications of surgery. Nevertheless, frequently a satisfactory beneficial response to radioiodine is delayed because of inadequate dosage. This disadvantage can prove to be an important economic factor since most of these patients are in the wage-earning age group. With routine pre-operative preparation, using iodine, calcium, phosphorus, and vitamin D, adequate

sedation, and rest together with a sufficient diet, most patients with Graves' disease can be adequately prepared for surgery in less than two weeks. Pregnancy is an obvious contraindication to the use of radioiodine, since the thyroid of the growing fetus will pick up and retain I^{131} after the age of 12 weeks. The carcinogenic effects of such intense local irradiation by the beta particle are not sufficiently known, and will not be known for some years. This is particularly important in the younger patients. Moreover, neither the general metabolic effects of the radioactive thyroxine produced nor the radiation effects on the gonads have been sufficiently studied.

Toxic Nodular Goiter

The plan for treatment of this type of goiter with radioiodine is similar to that of Graves' disease, except that more I^{131}, approximately 0.3 millicurie per gram, is required. Richards et al. reported 32 remissions in 37 patients followed for six months or more. Glands weighing 50 to 100 gm. required an average of 30.6 millicuries.

The advantages of treatment of this type of goiter with I^{131} are similar to those in Graves' disease. However, the disadvantages become more pronounced. (1) The incidence of carcinoma in a toxic nodular goiter is considerably higher than in a toxic diffuse gland. (2) As shown in our clinic by Leblond et al., the rapid turnover and consequent uptake of I^{131} by a toxic nodular goiter are not in the large nodules, but rather in the paranodular tissue. Therefore, the reduction of size is less than in a toxic diffuse goiter. (3) The larger glands (over 150 gm.) require considerable quantities of I^{131} and the chances of carcinogenesis would thus seem greater.

Thyroid Malignancy

It is well known that ionizing rays in sufficient quantities, such as in roentgen irradiation, can produce complete destruction of neoplastic cells. When the malignancy is deep-seated, however, a sufficient cancerocidal dose cannot usually be delivered owing to simultaneous destruction of the intervening tissues. Thus, it has long been the aim of the investigator to find some irradiating chemical substance which will specifically localize in neoplastic cells and do little or no damage to the neighboring tissues. The discovery of the first isotope of iodine thus gave new hope in the treatment of thyroid malignancies, since the thyroid gland has such a great avidity for iodine. This attraction for a specific element is unequaled by any other organ in the human body. Consequently, it was with great disappointment that Hamilton et al. reported their observations of the failure of uptake of radioiodine in 2 patients with thyroid malignancy.

It was not until 1946 that Seidlin et al. reported the first instance of selective uptake of I^{131} by metastases of a thyroid carcinoma, with subsequent unmistakable therapeutic improvement in the patient's over-all condition. Since then numerous clinical investigators have reported on the varied actions of this isotope in the treatment of metastatic as well as localized cancer of the thyroid.

The thyroid gland, as do certain other organs, presents real problems in the differentiation of its benign and malignant tumors. Owing to the proximity of important structures, radical surgery of the neck carries a high morbidity from

the functional standpoint as well as from the eventual cosmetic effect. It thus becomes imperative that thyroid surgeons appreciate the various problems encountered in making a diagnosis of thyroid malignancy and in specifying the type present. The suitable definitive therapy consequently lies in their hands.

An epithelial tumor may be considered to be carcinoma when it has shown clinical or microscopic evidence of malignancy, characterized by one or more of the following criteria: (1) local invasion, (2) vascular invasion, (3) recurrence (of the original tumor) after incomplete excision, (4) metastasis, and (5) death of the patient due to its invasive character.

Most tumors of the thyroid may be placed in one of three major histologic categories: First is the *papillary carcinoma* which is so prevalent in the younger age group, especially children. It grows slowly, spreads primarily to the regional lymph nodes, and is generally amenable to surgical excision. Second is the *adenocarcinoma* which usually occurs in the middle-aged group. It grows with moderate rapidity and often spreads by the blood stream to produce scattered metastases in the lungs or bones. The multiplicity of metastases frequently contraindicates surgery. Third is the *undifferentiated* type of tumor, which grows so rapidly that usually by the time the patient comes to surgery the entire gland is diffusely infiltrated and the neck is "cemented" by tumor tissue, making total excision dangerous and in certain patients impracticable.

Radioactive iodine has thus far proved of greatest value in the therapy of the second type of lesions, the *adenocarcinomas*. This is because physiologically adenocarcinoma more closely resembles normal thyroid tissue than do the other types and consequently *takes up and stores more I^{131}*. One is not to conclude that I^{131} should not be tried in the other types, but rather that other forms of therapy, notably surgery and/or roentgen irradiation, which are known to yield beneficial results, should be the main form of treatment. In fact, radioiodine should usually be limited to those lesions of adenocarcinoma which are inaccessible to surgery.

The quantity of radioiodine used to locate distant metastases will depend on the case at hand. When patients are referred to a radioiodine center prior to surgery, frequently the diagnosis is questionable and should be accurately determined. A heavy tracer dose of 1 millicurie may be given to obtain autoradiographs after surgery. When the clinical diagnosis is obvious, characterized by a "frozen" neck with or without metastases, larger doses may be given preoperatively in order to obtain better autoradiographs. If the patient is referred postoperatively with a questionable diagnosis, and no known metastases are present, doses of 1 millicurie are adequate in order to make a survey for hidden deposits. If the patient is seen postoperatively with unquestionable clinical and microscopic diagnoses, it is preferable to give doses of the order of from 10 to 25 millicuries in making the survey for metastases. Doses over 1 millicurie should generally be limited to those patients who will receive further treatment with I^{131}, or for advanced or terminal cases where larger doses may yield significant information. The advantages and disadvantages of the variously sized doses must be evaluated for each patient.

After the administration of I^{131} a portable G-M tube is usually employed in scanning the patient, in order to determine the uptake (Fig. 1). This is usually done 24 hours after administration of several millicuries, or four or five days after

sedation, and rest together with a sufficient diet, most patients with Graves' disease can be adequately prepared for surgery in less than two weeks. Pregnancy is an obvious contraindication to the use of radioiodine, since the thyroid of the growing fetus will pick up and retain I^{131} after the age of 12 weeks. The carcinogenic effects of such intense local irradiation by the beta particle are not sufficiently known, and will not be known for some years. This is particularly important in the younger patients. Moreover, neither the general metabolic effects of the radioactive thyroxine produced nor the radiation effects on the gonads have been sufficiently studied.

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stained tissue and is developed and mounted without moving. In this manner a more precise localization of the uptake may be obtained (Fig. 6).

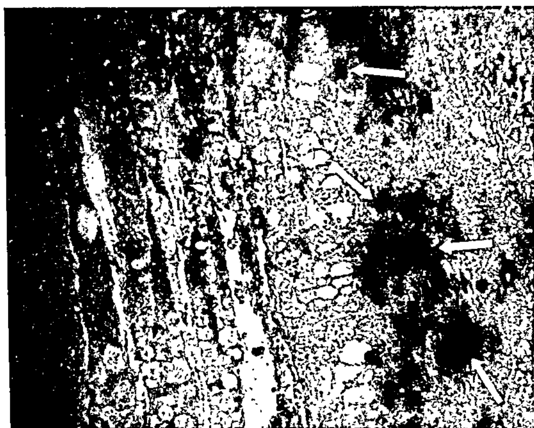


Fig. 6.—Autoradiograph of the same tissue shown in Fig. 5. In this technic, the emulsion was painted over the tissue where it remained through the subsequent processing. The arrows point to the areas of radioactivity. Note that the tumor tissue on the left retains no I^{131}.

When the normal thyroid gland ceases to function, it is thought that the increased thyrotropic hormone (TSH) formed by the anterior pituitary will stimulate the neoplastic cells to function more like normal thyroid cells and thereby again trap I^{131}. A state of myxedema is frequently necessary before the neoplastic cells will be stimulated enough to demonstrate uptake subsequently. Figure 7 is an autoradiograph of a 15 year old boy with functioning thyroid metastases in the lungs. This patient had received 150 millicuries of I^{131} during an eight month period prior to this pulmonary biopsy and was slightly myxedematous. It frequently becomes necessary to relieve this state of myxedema with suitable thyroid medication. Its continued use abolishes all uptake of I^{131} for a month or more. As further support for this effect of thyrotropic hormone Trunnell et al. have significantly increased the uptake of thyroid metastases with thiouracil and TSH in patients receiving thyroid medication.

When the decision has been made to treat a patient with radioiodine, the isotope can be administered either in small amounts every few weeks or in large doses every few months. The advantage of the frequent small doses lies in the fact that different parts of the lesion will pick up I^{131} at different times. In this

amounts larger than 25 millicuries. The entire body is carefully searched for areas of unusual uptake. Depending on the time interval, there will be some I^{131} in the gastro-intestinal tract and in the area of the urinary bladder. If normal thyroid tissue remains in the neck, most of the trapped I^{131} will be found in that region. If any unusual area of uptake is found, quantitative studies are subsequently made and the patient is x-rayed to ascertain any radiographically visible lesion.



FIG. 5—Section of an undifferentiated carcinoma (A) of the thyroid surrounding a bit of normal thyroid tissue (B). From the autoradiograph on the right, it is apparent that only the bit of normal thyroid tissue retained the I^{131} as shown by darkening of the emulsion.

The uptake of I^{131} by widely scattered metastatic lesions depends on their degree of function. It has been found that but few metastatic thyroid deposits take up I^{131} *until all normal thyroid tissue is removed,* by surgery, x-ray, or I^{131} therapy. Therefore, a negative scanning for uptake in metastatic lesions in a patient who has residual thyroid tissue in the neck is in no way conclusive.

When surgery is performed following the administration of 1 millicurie or more of radioiodine, autoradiographs may be obtained to show the radioiodine uptake by the neoplastic tissue. The stained microscopic section is dipped into 1 per cent celloidin; a light-sensitive film is placed over this and exposure is continued for several days. The film is then developed and, as shown in Fig. 5, the uptake in the tissue can be readily determined. To localize this more exactly, the technic of Leblond is necessary, whereby the emulsion is painted on the

SUMMARY

Radioactive iodine, I^{131}, has been used in the study and treatment of human thyroid disease for the past 10 years. The use of this and other isotopes has made it necessary that the physician have a basic understanding of the nature of radioactivity and the various ways by which its effects are brought about.

By far the most important contribution of radioiodine to medicine has been in the study of normal and pathologic thyroid physiology. Having certain physical attributes not possessed by the stable I^{127}, radioiodine has been used to determine qualitatively as well as quantitatively the *manner* and *rate* of turnover of iodine by the thyroid gland. These are the bases for the familiar radioiodine "tracer" studies of thyroid activity.

Furthermore, radioactive iodine has a definite, though limited, place in the treatment of thyroid malignancy. The most encouraging results have generally been in the colloid-forming adenocarcinomas.

It will only be through continued research that greater numbers of patients will find relief from thyroid disease by means of this new form of internal radiation.

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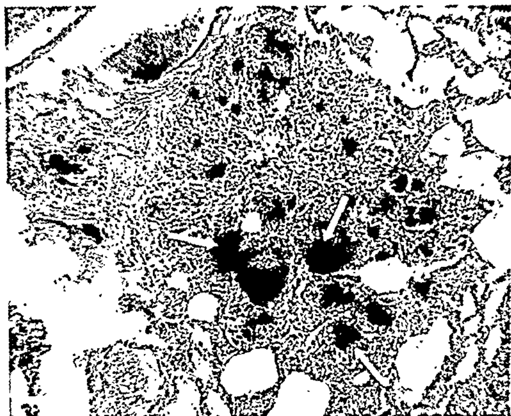


FIG. 7.—Autoradiograph of a functioning pulmonary metastasis of an adenocarcinoma of the thyroid. The arrows point to the area of radioactivity. This tissue was removed by a lung biopsy.

The total amount of I^{131} that can safely be given to a patient depends on the amount and frequency of the doses, and on the percentage retained by the body. One millicurie of I^{131} delivers about one roentgen of *total body radiation*. A dose of 400 roentgens of total body radiation is frequently fatal. Trunnell et al. reported an instance in which a total of 638 millicuries, given over a period of several months, produced a fatal panhematocytopenia. Obviously, in patients treated with therapeutic doses of I^{131}, frequent studies should be made of the peripheral blood and bone marrow as these tissues generally first show irradiation effects.

Radioactive iodine has been most widely used in the treatment of thyroid malignancy. The best results have been obtained in the scattered metastases of adenocarcinoma since these cells most closely resemble normal thyroid tissue in their I^{131} uptake. Although actual "cures" will probably be few in number, many patients treated with radioiodine should experience months or even years of real subjective improvement and well-being.

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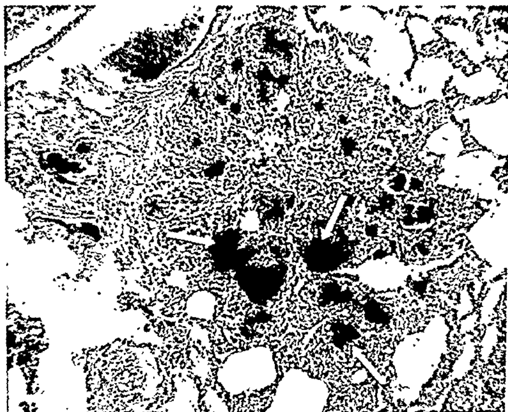


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advantages. This technic appears to increase quickly the perfusion of the coronary arteries which, in turn, will guarantee more efficient cardiac function. It is also possible to maintain a systemic pressure at a known level by adjusting the apparatus through which the blood is delivered. And the danger of rapid overloading of the vascular system is minimized.

It should be noted, however, that recent experimental work by Blades and Beattie indicates that there are real dangers if too large amounts of intra-arterial transfusions are given and that after a reasonable systemic blood pressure has been established by the arterial route the blood should be given by vein to maintain blood volume.

Medication

In the past there has been considerable disagreement concerning the use of morphine and other narcotics in patients with chest wounds. There appears to be no set formula which will be satisfactory in all conditions. If morphine is used, however, it should be given cautiously and preferably by the intravenous route, because in the shocked patient the absorption of the drug when given subcutaneously is low. If the doses are repeated once blood volume is restored and shock relieved, the patient may suffer from morphine poisoning.

Most of the pain following thoracic wounds results from injury to the chest wall. The pain can usually be controlled with small doses of narcotics and the proper use of procaine injections to block the sensory nerves of the part injured.

The Chest Wall

The seriousness of chest wall injuries depends on the effects of the mechanics of respiration. This is of particular importance when the muscles controlling inspiration are affected. Ordinarily if one unit of muscle is injured compensatory action by others will furnish a reasonable factor of safety. Unless extensive destruction of the chest wall has taken place, the immediate effects on respiratory exchange will depend on the amount of associated pain which in turn will cause splinting of the thorax and decrease in respiratory movements.

One method for partial control of pain after simple injury to the chest wall is the application of adhesive strapping to the thorax to minimize respiratory excursions. The most efficient type of chest strapping involves encircling the entire lower costal margin which will result in partial immobilization of the entire bony thoracic cage. Other types of strapping are of little value.

The advantages of regional nerve blocking for control of pain in the chest wall have practically eliminated the need for strapping of the thorax after rib fractures. In minor injuries, after a patient is ambulatory and is annoyed by some pain, a support in the form of a polo belt or an Ace bandage may be useful. In severe injuries, however, adhesive strapping is not only inefficient, but it can be dangerous if vital capacity has already been decreased as a result of the injury.

Regional Nerve Blocks

Injections of procaine, either in the site of rib fractures or by paravertebral nerve blocks are highly successful in controlling chest wall pain. Most surgeons

The Management of Acute Chest Injuries

BRIAN BLADES, M.D. AND R. CARL GARBY, M.D.

Thoracic injuries may involve damage to the chest wall, the lungs, or any of the viscera contained within the bony thoracic cage. To ensure the greatest possible safety, the possibility of visceral injury in all cases of thoracic trauma must be considered. And certain features peculiar to chest wounds deserve special emphasis.

GENERAL CONSIDERATIONS

Shock

The accepted methods for combating shock which may be applied after injuries to all parts of the body should be instituted in all cases of chest trauma. It is important, however, to emphasize a feature peculiar to thoracic wounds which may be a factor in producing shock when the lungs are damaged. Accumulations of blood or mucus in the trachea or bronchi may interfere seriously with pulmonary ventilation. If respiratory exchange is compromised by the accumulation of secretions, aspiration through a bronchoscope or by catheter suction may result in a dramatic change in the patient's condition.

Pulmonary edema or massive hemorrhage into the lung parenchyma causes a more serious problem, which is best treated by oxygen therapy. The possibility of partial suffocation must, however, be considered in every patient with a thoracic wound who is in shock.

The reports of Beecher and others during the last war have established the dangers of overloading the circulatory system with blood and plasma in a shocked patient. This is particularly true in the cases with injury to the lung. The physiologic changes in shock and acute hemorrhage are similar, characterized by fall in blood pressure, increased pulse, slowing of circulation, and loss of blood volume. Anoxia will produce increased capillary endothelial permeability which will finally result in tissue and pulmonary edema and, eventually, death, if not relieved.

Although the average war wound will exceed in severity most wounds incurred in civil life, the same principles may be applied, and are of particular importance in the poor risk patient, the elderly, or the horribly injured subject.

Transfusions of Blood

The importance of transfusions of blood in traumatic shock cannot be questioned, but it is important to give reasonable quantities as slowly as possible to meet the fluid requirements. In this connection the role of intra-arterial transfusions should be mentioned. After massive hemorrhage from any cause, resulting in severe shock, the administration of blood by the arterial route has certain

level on the anterior chest wall. By this method a constant intercostal block can be maintained for hours or days if necessary.

The seriousness of chest wounds usually depends on the amount of visceral damage. Multiple fractured ribs are painful and are dangerous if associated pain causes severe splinting of the thorax or the lungs are torn by jagged fractured ends.



FIG. 1.—Photograph of plastic tubes being placed in the wound after a thoracotomy.

THE STOVE-IN CHEST

A common severe injury to the thoracic cage may result from trauma to the anterior chest wall and sternum, the force of which may be transmitted posteriorly causing fractures to the posterior ribs over the transverse processes, which act as fulcrums. Multiple bilateral fractures, both anteriorly and posteriorly, associated sometimes with a fractured sternum, may partially or completely detach segments of the chest wall. This will, of course, result in serious interference with the bellows-like action of the thoracic cage. Moreover, after such severe damage to the chest wall, there is usually associated visceral injury. Paradoxical motion which will result from the increased negative intrapleural pressure on inspiration, sucking in the detached portion of the chest wall, may so reduce respiratory exchange that death will follow.

Traction may be placed on the sternum to hold it fixed in position by placing towel clips in the bone and applying traction with a frame, rubber bands, or

prefer paravertebral blocks, which may be done with the patient lying in the prone position or on his side.

After skin preparation an intradermal wheal of novocain may be placed near the spine at the desired rib level. The position of the wheal should be just caudal to the lateral spinous process of the vertebra because the posterior spines of the dorsal vertebrae extend caudally to overlap the vertebra below. A 3 inch, 20 gauge needle may be employed and is passed through the wheal of novocain and advanced slightly upward and medially until the transverse process of the vertebra is located. Using the lower border of the transverse process for a guide, the needle is advanced about 0.5 cm. and the plunger of the syringe is withdrawn to be sure that the tip of the needle is not in a blood vessel or the subarachnoid space. Five to 10 cc. of 1 per cent procaine solution are injected. When paravertebral block is to be employed, at least two intercostal nerves above and below the level of the injury should be injected.

Methods for Prolonged Intercostal Nerve Blocks. It has been noted by Burford, Samson, Brewer, and others that sometimes a single intercostal nerve block or two or three repetitions of the technic will furnish long-standing or permanent relief of pain. Unfortunately, however, this is not always the case and recently a technic developed by Blades and Ford has been employed to produce intercostal analgesia for many hours or several days. The method was originally used following elective operations on the chest but should have wide application in cases of acute trauma when certain modifications are employed.

The method consists of placing small plastic tubes in the wound through which procaine solution can be delivered at two to three hour intervals. In cases in which open thoracotomy is necessary, after closure of the pleura and intercostal muscles the tubes are placed at the inferior border of the ribs (usually four tubes are employed) in the extreme posterior position just anterior to the erector spinae muscle. The tubes are secured in place by a few fine silk or catgut sutures and for convenience are brought out the anterior angle of the wound so that injections may be done without turning the patient. The tubes are usually placed on 19 gauge needles which have been anchored in a cork and the needles are covered with a sterile rubber cap (Fig. 1). The technic has been highly successful following elective thoracic operations and there is no reason to doubt its value after thoracotomy for acute injuries to the thorax.

A slight modification of the method has been developed for use in patients with nonpenetrating wounds of the chest, or in situations where a large thoracotomy incision is neither necessary nor desirable.

A short incision, approximately 5 cm. in length, is made parallel to the spine over the posterior portion of the rib, at the level of injury, to gain access to the sensory nerves supplying the region. Three or four ribs are exposed corresponding to the level of the pain. A long needle is then inserted through the intact skin in the midaxillary or anterior axillary line, pushed through the muscles of the chest wall and located with the tip of the finger which is placed in the posterior wound. Plastic tubing is then threaded through the needle, secured in place at the inferior border of the rib, and the small incisions parallel to the spine are closed. Procaine may then be injected through the tubes which are at a convenient

wise or impossible. If there is a contused wound with associated tissue damage débridement may be necessary before final closure is done. This will, of course, require operating room facilities. Regardless of the technic employed, it is important to emphasize that the physiologic bellows action of the chest wall must be preserved as much as possible. If large defects in the chest wall are encountered, the defect should be closed with as little tension as possible. Long releasing incisions in adjacent skin will make it possible to repair even huge wounds.

INJURIES TO THE LUNGS

In both penetrating and nonpenetrating varieties of wounds, the lungs are more commonly injured than any other thoracic viscera. Damage to the lung may result in hemorrhage producing hemothorax, bleeding into the lung parenchyma proper, pneumothorax, or emphysema.

Hemothorax

Injury to the pulmonary parenchyma may cause bleeding from either a pulmonary artery or pulmonary vein. The pressures in the pulmonary system vary from 20 to 30 mm. of mercury and although bleeding from these vessels may be rapidly fatal, hemorrhage usually ceases because the elastic vessel walls contract into lung tissue. Fatal hemorrhage is uncommon except in instances of extensive wounds involving major pulmonary vessels. Hemothorax of demonstrable proportion will be found in the great majority of serious thoracic wounds (Fig. 2).

Once hemorrhage has ceased to be active and shock is controlled, early expansion of the lung should be accomplished by aspiration of the blood from the pleura. If the loss of blood has been massive with collapse of the lung and a mediastinal shift, emergency aspirations may be necessary to adjust intrapleural pressures to the level compatible with comfortable respirations. Experiences during the past war have largely erased the fear that early evacuation of blood from the pleura might result in secondary hemorrhage and the practice of delayed aspiration or employment of air replacement when blood is removed to prevent rapid re-expansion of the damaged lung has been abandoned. The primary objection to this technic is that failure to remove the fluid, or air replacement, will keep the lung in a collapsed position which not only reduces pulmonary function but if continued may result in chronic hemothorax requiring open operation and decortication to free the fixed lung. Moreover, the entire pleural space becomes vulnerable to infection. If the blood is evacuated early without air replacement, the pleural space will be occupied by the re-expanded lung and if a complicating empyema should occur it will be of small volume.

The necessity for emergency thoracentesis in cases of hemothorax can be based on clinical manifestations. A sufficient amount of blood should be removed to relieve dyspnea and to allow the mediastinum to occupy its normal midline position. After the patient's condition is stabilized and the gradual evacuation of the hemothorax is undertaken, the amount of blood which may be removed will vary from patient to patient. No complicated apparatus or pressure recording machines are necessary in determining the amount of blood which may be removed with safety at each aspiration. When the thoracentesis is begun the patient

other mechanical methods. *The relief of pain by paravertebral block is of* particular importance in patients with a stove-in chest.

Recently Carter and his associates have advocated the performance of tracheostomy in patients with severe crushing injuries of the chest. Their treatment offers two advantages. First, it is easy to remove the accumulated secretions from the trachea and bronchi if a tracheotomy tube is in place, and, second, and perhaps of more importance, the dead space of the upper airway will be reduced if the air intake is at a lower level. If one remembers that a minimum of approximately 500 cc. of air is necessary for tidal air to maintain adequate ventilation and that the average dead space level of trachea, bronchi, and so forth is about 150 cc., it becomes apparent that reduction of dead space *might be a life-saving measure in the critically ill or moribund patient.*

Blood Vessels of the Chest Wall

Hemorrhage following either penetrating or nonpenetrating wounds of the chest is usually from the lungs. It is important, however, to consider the possibility of bleeding from the intercostal vessels or from the internal mammary arteries. Bleeding from the intercostal vessels is possible in the nonpenetrating wound, but unless associated with fractured ribs it is improbable. Bleeding from the internal mammary arteries is unusual unless there has been penetration of the chest wall.

In penetrating wounds the points of entrance and exit of a missile or of a knife may furnish some clues as to the source of bleeding from the chest wall. If there is any possibility of bleeding from the internal mammary vessels, exploration should be undertaken *unless the patient's condition precludes any type of surgical* intervention.

If *an intercostal vessel is completely divided, retraction of the ends of the* vessel into muscle usually results, causing the bleeding to stop. If, however, *there is a tear in the vessel wall,* the movements of respiration make it difficult for clotting to occur and for the bleeding to stop spontaneously. Recurrent intercostal hemorrhage demands exposure and ligation of the vessel.

Sucking Wounds

Wounds which have penetrated the pleura are usually apparent, but it is important that if there is any possibility of an opening into the pleural cavity a sufficient amount of clothing be removed, even under the worst conditions, to determine the nature of the defect. The necessity for prompt closure of sucking wounds has long been established and repeatedly emphasized. Openings larger than the trachea are more dangerous than the small defects, but the consequences of a sucking wound will depend on the vital capacity of the wounded man. A small defect in the chest wall of an elderly patient may easily be fatal, whereas the young, vigorous subject, whose vital capacity is excellent, may tolerate amazingly large defects. The extent of associated damage through hemorrhage in the lung will, of course, be a factor in the survival of the patient.

The method employed to close an open wound in the chest will depend on the conditions under which the wound has occurred and the materials at hand. Occlusive dressings may be utilized as a temporary measure if primary suture is un-

PNEUMOTHORAX

The seriousness and extent of pneumothorax following trauma will depend on the size of the bronchi which have been injured. Minor tears of the parenchyma and bronchioles will usually seal themselves and a tension pneumothorax will not develop. However, if a large defect in the lung has been created with injury to a good sized bronchus, air leakage may be rapid and fatal if not relieved.

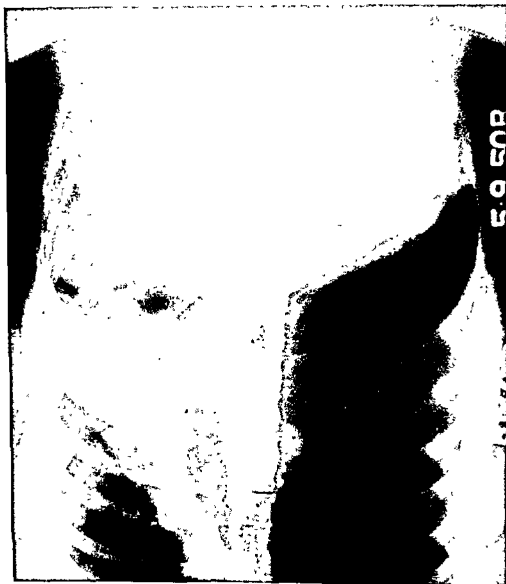


FIG. 3.—A roentgenogram showing a tension pneumothorax. Note the extreme shift of the mediastinum.

If a ball valve action is set up allowing air to enter the pleura and not escape, a tension pneumothorax may be rapidly fatal (Fig. 3). Under emergency conditions aspiration with syringe and needle should be carried out and decompression by catheter drainage with a water-seal attachment accomplished as soon as possible (Fig. 4). If decompression is done, even large defects will usually heal

should be instructed to inform the operator of any tightness he may feel in the chest during the course of the aspiration. This sensation will vary considerably in the individual patient. Sometimes the removal of 200 or 300 cc. of fluid will cause an uncomfortably tight feeling. In other subjects as much as 700 or 800 cc. or more of fluid may be removed. The sensation of pressure which may be followed by coughing results from increased negativity of intrapleural pressures as the aspiration proceeds, and the procedure should be discontinued as soon as this is noted. The gradual evacuation of the hemothorax may be continued from day to day or at two day intervals until re-expansion of the lung is effected. Failure to accomplish early pulmonary re-expansion will result in chronic hemothorax which usually requires open operation and decortication of the lung.

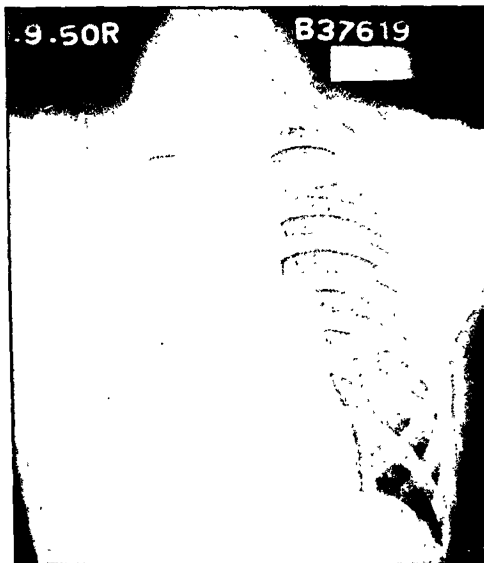


FIG. 2.—Roentgen appearance of hemothorax after a penetrating wound of the chest, inflicted with an ice pick.

spontaneously. Relief of rapidly increasing intrapleural pressures is the prime objective and if this is not accomplished death will result from suffocation.

The principles involved in the treatment of pneumothorax are simple and the recognition of the condition is easy if the possibility of pneumothorax is considered. It should be noted, however, that physical examination may be misleading even in cases of extensive pneumothorax. A roentgen examination of the chest is essential in all instances of thoracic trauma if possible and is of particular importance in establishing the presence of pneumothorax.

Fracture of Bronchus

It is possible under extraordinary conditions for a good sized bronchus to be fractured. The division of continuity may be complete or partial. More often than not associated injury to vessels and viscera will result in a rapidly fatal outcome. Survival from a fracture of the bronchus is more common in the young and the following findings should suggest the possibility of a fractured bronchus: a tension pneumothorax with associated subcutaneous emphysema and mediastinal emphysema with little or no evidence of fractured ribs, a minimal hemothorax in the presence of a tension pneumothorax and, finally, atelectasis of a lobe or a lung. Ordinarily a positive diagnosis is not made until after decompression of the tension pneumothorax and the persistence of atelectasis of the lung distal to the fracture. If a tentative diagnosis of fracture of a main bronchus is made an open operation should be performed immediately if the patient's condition will permit it.

Emphysema

Injury to the lung from fractured rib ends may result in subcutaneous emphysema of varying degree. Penetration of the lung at a point at which there is pleural symphysis will allow the air to take the line of least resistance into the tissues of the chest wall and particularly the subcutaneous tissues. The air may dissect its way into the neck, face, and sometimes over the entire body, and although the patient may have a perfectly horrible appearance, the danger to life if the air stays in the subcutaneous plane is not great. Several days or weeks may be required before all of it is absorbed, but the prognosis is good. Emphysema becomes dangerous if there is invasion of the mediastinum, which may result in mediastinal tamponade. This usually results from the injury of a large bronchus. Difficulty in swallowing and voice changes indicate some mediastinal involvement and should be considered as danger signals.

Simple subcutaneous emphysema requires no treatment. Mediastinal emphysema, if resulting from a tear of the large bronchus, may be treated by an attempt to repair the leak, or, if the site of the leak is unknown or the patient's condition precarious, a cervical mediastinotomy effecting an entry into the pretracheal and posterior visceral spaces will allow some air to escape and may be life-saving.

Subcutaneous emphysema may also be associated with a tension pneumothorax resulting from a stab wound or bullet wound. If pressures of the air in the pleura becomes excessively high, the air will seek the line of least resistance and find its way into the chest wall. Relief of the tension pneumothorax will stop the dissection of air and prevent further accumulation of subcutaneous emphysema.

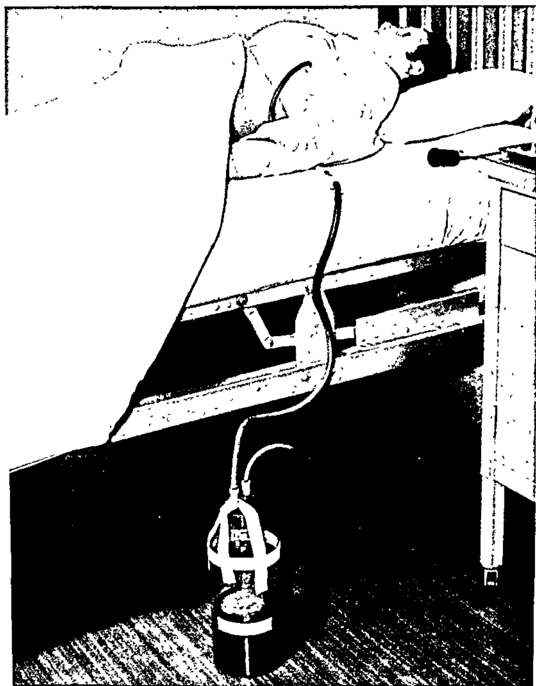


Fig. 4.—Water seal drainage for decompression of a tension pneumothorax.

precautions taken to prevent it. Relief of pain, early ambulation, and urging the patient to cough are valuable prophylactic measures.

If atelectasis is present it may be necessary to aspirate the tracheobronchial tree. This can be accomplished by passing a catheter into the trachea and applying suction, or better by direct visualization of the bronchi through the bronchoscope with removal of the obstructing material.

Traumatic Chylothorax

Injury to the thoracic duct is uncommon, as might be expected from the small diameter and protected position of this structure. Probably some minor injuries to it are sustained simultaneously with traumatic hemothorax, the diagnosis obscured by the presence of blood and the chylothorax cured by the same measures used for control of hemothorax. The causative injury may range from a severe crushing wound of the thorax to a minimal injury sustained perhaps several months prior to the onset of symptoms.

When the diagnosis of chylothorax is considered it is readily confirmed by aspiration of a milky fluid containing a large number of lymphocytes and eosinophils with a concomitant reduction of these elements in the circulating blood.

The danger of this condition, aside from the compression phenomena produced, lies in the rapid starvation which results from losing protein and fat from the body. For this reason corrective therapy should be instituted as soon as the diagnosis is established and must be as energetic as the individual situation requires.

Relief of increased intrapleural pressure is the most pressing consideration. Repeated aspirations may be all that is necessary, but if successive daily aspirations do not result in diminishing quantities of chyle, closed tube drainage should be instituted, and this is preferable to repeated aspirations.

These methods of therapy, of course, result in the loss of large quantities of chyle, and vigorous supportive treatment is required. This consists of a high protein, high vitamin, low fat diet, and transfusions of whole blood. Autotransfusion of the aspirated chyle has been tried with success in some cases, and death in others (Whitcomb and Scoville). Its use is not recommended.

Depending on the condition of the patient and the amount of chyle obtained from day to day, it may be necessary to perform an open thoracotomy. Obviously, if the amount of chyle poured into the thorax remains at a high level for more than a few days, the patient's condition will rapidly deteriorate and thoracotomy should be done before this occurs.

There has been considerable controversy (Hodges and Bridges; Meade, Head, and Moer) regarding the safety with which ligation of the thoracic duct can be performed, but in an otherwise healthy individual double ligation above and below the point of injury to the thoracic duct can apparently be done with impunity anywhere along the course of the duct. This should be done if the duct is injured during the course of intrathoracic or cervical surgery. It appears that only where a pathologic process such as a mediastinal lymphoma exists is there danger of this procedure being unsafe or inadequate.

An aid to the location of the thoracic duct and the injury to it is the ingestion by the patient of a coal tar lipophylic dye, such as Sudan III, a few hours before surgery. If a green dye is used good color contrast is obtained (Klepser).

Radiographic evidence of a localized pneumonitis sometimes follows peripheral lung tissue injury, as by a through-and-through bullet wound. This is characterized by an ill defined area of infiltration which becomes more sharply outlined and rounded and then becomes smaller and disappears (Evans). Pathologically it is due to local parenchymal hemorrhage. Usually no therapy is required for this manifestation of the wound.

Atelectasis

Depression of the cough reflex associated with accumulations of blood or mucus may result in atelectasis of the lung. The extent of the lesion may vary from total atelectasis involving the entire lung (Fig. 5) to involvement of one or more of the various pulmonary segments.

The possibility of atelectasis should always be considered and appropriate



Fig. 5.—Roentgenogram demonstrating complete atelectasis of the right lung.

superficial appearance of drunkenness are the result of cerebral anoxia as cardiac function is increasingly embarrassed by the tamponade.

Blood or fluid in the pericardium of sufficient quantity to produce a fall in systolic pressure, narrowing of pulse pressure, and other manifestations of cardiac tamponade requires immediate treatment. There is some difference of opinion in the details of treatment of traumatic hemopericardium. In the past some surgeons have insisted on immediate operation. In recent years, Blalock and others have advocated trials of aspiration of blood from the pericardium to relieve the pressure and to postpone operation until it is evident that there is a constant leak of blood. In the past decade there has been a tendency to adopt a conservative attitude in the case of hemopericardium and try aspiration before an exploratory operation and suture of the laceration is attempted. The choice of the conservative or radical approach is not nearly so important, however, as the early recognition of the condition. Some advantages of preliminary aspiration to relieve pressure effects are that in some cases the bleeding will stop and with blood replacement either by intravenous or intra-arterial routes, the patient can be improved tremendously even if subsequent open operation and suture of the laceration is necessary. Regardless of the ultimate treatment it is important to prepare for open operation and aspirations of the pericardium should be done in the operating room and the patient left on the operating table until it is certain that further leakage will not occur.

THE MEDIASTINUM

Wounds of the mediastinum from external trauma, e.g., bullet wounds, stab wounds, and so forth, are usually fatal if the great vessels are involved. Penetrating wounds of the trachea and esophagus may occur without blood vessel damage and can be treated successfully. Perforation of the esophagus with the esophagoscope or gastroscope is probably the most common type of injury of all of the organs located in the mediastinum. Injury to the trachea and main bronchi with the bronchoscope can occur, but is rare.

Before considering the various consequences of external and internal trauma to the mediastinal structures, it is important to review certain anatomic and physiologic characteristics of the mediastinum which affect surgical intervention.

Surgical Anatomy. In considering the surgical anatomy of the mediastinum, it should be emphasized that the various compartments are actually potential spaces and do not become apparent in the living patient unless they contain air or fluid. Complete anatomic descriptions of the mediastinum are somewhat bewildering, but the spaces of importance to the surgeon are three in number and are easily defined. They are the posterior visceral space, the pretracheal space, and the previsceral space (Fig. 6).

(1) Posterior Visceral Space: The posterior visceral space extends from the level of the retropharyngeal space to the diaphragm. It is apparent that injury to the esophagus is likely to cause infection of this compartment.

(2) Pretracheal Space: The pretracheal space extends from the neck to the level of the great vessels and the bifurcation of the trachea. Here it is sharply limited by fascia and infections of this space will rarely extend beyond this anatomic boundary.

WOUNDS OF THE HEART

The heart may be injured either by a penetrating or nonpenetrating thoracic wound. In most cases, however, heart wounds which are amenable to surgical intervention are the result of stab wounds with ice picks, knives, and other small weapons. Through-and-through bullet wounds of the heart are almost always fatal.

Severe nonpenetrating wounds may contuse heart muscle and injure it enough to cause bleeding into the pericardium and produce a cardiac tamponade. The successful management of wounds of the heart depends on awareness of the possibilities of bleeding into the pericardium and prompt treatment. Obviously if a wound is in the general region of the heart the possibility of cardiac damage must be considered. In this connection, it is important to determine if possible the type of weapon employed, the length of the weapon, and the direction of the thrust, if it be a stab wound. It is also important to remember that small missiles may be deflected by bone or soft tissue and follow bizarre patterns of penetration.

Cardiac Tamponade

The classic manifestations of cardiac tamponade are a weak, feeble pulse which is rapid, decreased systolic blood pressure, increased venous pressure, and narrowing of pulse pressure. Cardiac sounds are absent or diminished. The rapidity of onset of these manifestations will depend largely on the volume of blood leaking into the pericardium.

In any patient in whom there is a possibility of a wound of the heart, blood pressure, pulse pressure, and pulse should be checked at 15 minute intervals until one can be sure that a cardiac tamponade is not developing. Clinical impressions of venous pressure may be misleading and the venous pressure may rise to alarming heights before it becomes apparent on gross examination.

A roentgenogram of the chest is not helpful and may be misleading as far as establishing the diagnosis of cardiac tamponade. Since one rarely has knowledge concerning the size of the cardiac silhouette before wounding, the roentgen film of the chest will not be of significance until the cardiac silhouette has increased in size appreciably. If one waits until the cardiac shadow, as seen on the roentgenogram, is diagnostic of fluid in the pericardium the clinical situation has usually reached a dangerous stage. Examinations with the fluoroscope, however, may be helpful in that an idea of the movement of the heart can be established. It should be emphasized that the diagnosis of cardiac tamponade should be at least suspected without the aid of roentgen studies.

In patients with stab wounds of the heart, there may be an initial period of unconsciousness as a result of the wounding and primary bleeding. This may be followed by a lucid interval in which consciousness is regained and the wounded man may even walk about and appear to have no serious injury. Subsequent bleeding causes the tamponade to increase and a second period of unconsciousness will occur and if the lesion is not relieved death will certainly follow. It is important to note also that during the lucid interval the patient may appear to be intoxicated or even maniacal. And if the wounded man has been drinking, the entire clinical picture may be grossly misleading. The maniacal tendencies and

superficial appearance of drunkenness are the result of cerebral anoxia as cardiac function is increasingly embarrassed by the tamponade.

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(3) Previsceral Space: The previsceral space may be involved in a general mediastinitis, but is infrequently the site of an isolated infection. It is conceivable that contamination from operations of the neck might cause this to happen; or a stab wound at the level of the second rib anteriorly.

It is apparent from the anatomic position of these compartments that drainage may be effected either through the neck or by transthoracic route. Unless the infection or injury is known to be in the lower portion of the thorax, the cervical approach is usually adequate.

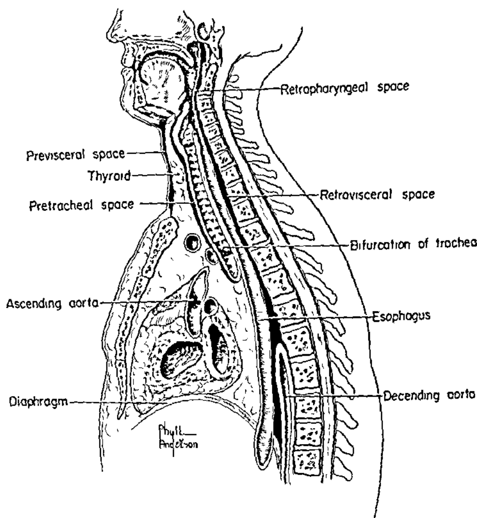


Fig. 6.—A diagrammatic drawing of the mediastinal spaces of particular importance to the surgeon.

Physiologic Considerations. Injury to the trachea or esophagus may result in mediastinitis or mediastinal tamponade or both. If the mediastinal pleura remains intact, leakage of air and fluid in a closed space may produce rapidly fatal tamponade. The clinical manifestations are similar to those of cardiac tamponade plus the presence of subcutaneous emphysema in the neck and chest wall. A tear in the mediastinal pleura at the time of injury will allow the air to enter the

pleura, producing a pneumothorax. Injuries of the trachea or main stem bronchi will result in a rapid production of subcutaneous emphysema. Air leakage from esophageal wounds is slower. In the case of suspected or proved mediastinal tamponade, decompression by mediastinotomy is a real surgical emergency. This may be accomplished by a cervical or thoracic mediastinotomy, depending on the level of the injury.

Mediastinitis. Contrary to older opinions the mediastinum has considerable resistance to infection. There should be no hesitation in performing mediastinotomy if there is any chance of perforation of the esophagus or trachea. Procrastination, which may allow the development of a generalized mediastinitis, usually results in a fatal outcome. In this connection it is important that the various antibiotics may diminish the severity of the mediastinitis but will not cure it and do not alter the basic principles of the immediate drainage of suspected or proved mediastinitis.

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Incontinence in the Female: Introduction

JOE V. MEIGS, M.D.

THE SIX PAPERS in this section dealing with incontinence of urine in the female are an excellent indication of the difficulty of the treatment of this unfortunate condition. Lack of urinary control when coughing, sneezing, or exercising is a miserable thing for these afflicted women. No doubt many simple surgical procedures will cure or relieve the situation but failures are not uncommon after the most careful treatment of the so-called sphincter muscles. In this symposium an attempt has been made to present the physiology of incontinence and the etiology of lack of control and the cure—both medical and surgical. In many instances exercise, as suggested by Kegel, will suffice, but in other instances his exercises may be necessary to strengthen the muscles both before and after a surgical procedure. It has always been my feeling that proper support of the internal sphincter muscle will eventually allow it to regain its tone and thus relieve the incontinence. In other words, it is the internal sphincter muscle which is weakened and stretched. The roof of the urethra behind the symphysis *is not loosened* from its tight fascial and connective tissue support by birth or other injuries, but the floor of the urethra at the internal sphincter area is loosened by tears at childbirth and by prolapse, cystocele, and urethrocele and thus *cannot close sufficiently* to control the outlet of fluid (urine). The replacement of the floor of the urethra thus giving the sphincter muscle the opportunity to regain its tone will cure the difficulty, provided the support is sufficient and a recurrence of the stretching does not occur. With the finger pressed lightly on the urethra, incontinence on coughing or sneezing will not take place. Thus it is evident that a sling operation or a build-up from below will relieve *the incontinence*, provided this pressure can be made constant. Each one of the following papers describes each author's method of applying pressure to the neck of the bladder and the internal sphincter mechanism, thus curing *the fallen urethral floor*. Each of the methods of treatment and explanations of the cause of incontinence is in the main based on proper support of the internal sphincter. This then is the essential part of the surgery for incontinence. What is *the most satisfactory* method to hold up the floor of the urethra and thus stop the stretch of the internal sphincter?

The six following papers are written by experts and without doubt will suggest to us some way to attack *the discouraging problem* of incontinence of urine of the stress type.

The Etiology of Urinary Stress Incontinence

S. RICHARD MUELLNER, M.D.

URINARY STRESS INCONTINENCE was formerly ascribed to torn urethral sphincters as a result of childbirth or to obstetrical injury of the bladder supports. In recent years, a number of investigators, among them Ingelman-Sundberg, Millin and Read, and Trahey and Pacey, independently of each other, have surmised that stress incontinence is due to the descent of the bladder neck. It has been difficult, however, to prove the precise pathologic physiology of urinary stress incontinence, because the mechanisms responsible for urinary control in women were not at all clear. Nor was it known how normal women initiate and stop the urinary stream at will. Until these basic problems were solved, the cause of stress incontinence of necessity remained obscure.

In 1945, a study of the physiology of micturition was initiated at the Beth Israel Hospital (Boston), utilizing the direct observation of the bladder on the fluoroscopic screen. The results of this study clarified the basic principles of the physiology of micturition. Once the normal physiology of micturition and of urinary control was established, the precise lesion of urinary stress incontinence could be readily demonstrated (Muellner; Muellner and Fleischner).

The technic of bladder fluoroscopy is quite simple. The bladder is first filled through a no. 16 F. catheter with a contrast medium consisting of a 5 per cent solution of sodium iodide to which a 20 cc. ampule of aqueous diodrast (35 per cent by volume) had been added. After 200 to 250 cc. of this mixture are instilled, the catheter is withdrawn. The bladder is then observed with the subject supine, standing, or turned to one side or to the other. The effect of coughing and straining on the bladder and on its supports, and the events at the beginning of micturition and when it is deliberately stopped are then accurately observed. Spot films are taken from time to time. A specially designed urinal, made of lucite, is used to obtain an unobstructed view of the bladder during micturition (Fig. 1).

PHYSIOLOGY OF MICTURITION AND OF URINARY CONTROL IN NORMAL WOMEN

In the normal nullipara, while recumbent, the bladder silhouette as seen on the fluoroscopic screen is like that in Fig. 2. The bladder base line is located near the upper border of the symphysis pubis. This position of the bladder is maintained when the subject stands up. On coughing the impulse from the increased intra-abdominal pressure is dissipated along the dome and to the sides of the bladder. The bladder base is, however, resilient and remains well supported.

Compared with its position in the nullipara, the bladder sits slightly lower in

the pelvis of the continent multipara while she is supine. The erect posture and sudden stress have a similar effect on the bladder, except that the bladder base sinks somewhat lower in the pelvis on standing. On coughing and straining the entire bladder base descends as a result of the sudden increase in intra-abdominal

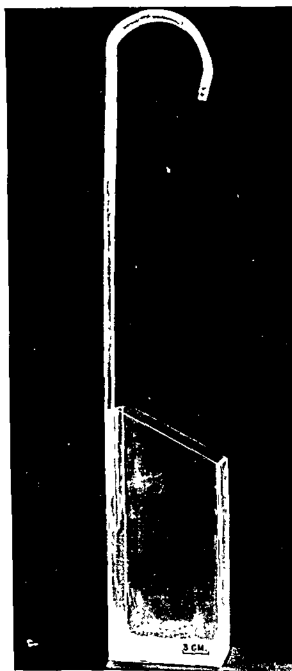


FIG. 1.—Lucite urinal. Note the long handle.

pressure. The bladder supports in the continent multipara are therefore more relaxed and yielding than they were before childbirth had caused them to lose some of their original tone. Nevertheless, mere general relaxation of the bladder supports does not impair urinary control (Fig. 3).

When the normal woman is asked to void the first visible step in voluntary micturition is not a contraction of the detrusor, as we have been led to believe, but consists rather of a "downward tug" in the region of the internal sphincter. This "downward tug" is actually a "downward push" of the internal sphincter and is brought about *in the following manner: The thoracic diaphragm is fixed* at the end of a brief inspiration and the lower portion of the abdominal wall is

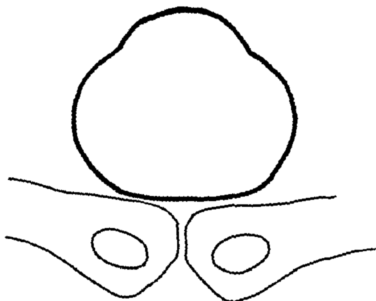


Fig. 2A.—Diagram of the bladder of a nullipara in recumbent position.

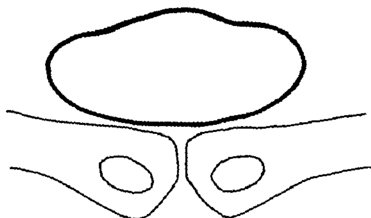


Fig. 2B.—Diagram of the bladder of a nullipara in the erect position. Note that the bladder has flattened out somewhat, but that it maintains the same relationship to the symphysis pubis.

contracted. These two maneuvers increase intra-abdominal pressure, which is directed precisely toward the internal sphincter. It is not generally appreciated that man accurately directs his intra-abdominal pressure toward the bladder neck for micturition, and toward the anus for defecation. The pelvic floor becomes relaxed so that the internal sphincter is pushed downward in the pelvis and thus becomes the most dependent point of the bladder (Fig. 4). The "downward

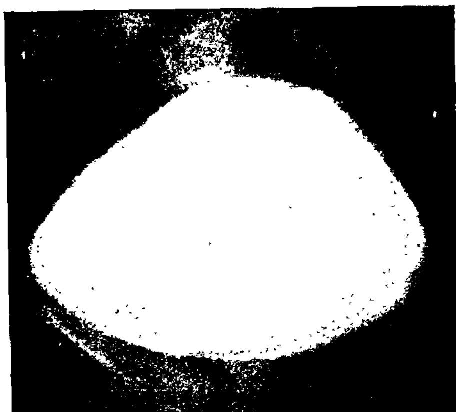


Fig. 2C.—Nullipara recumbent. Note the position of the base of the bladder.



Fig. 2D.—The same nullipara, erect. Note that the bladder maintains the same relationship to the symphysis pubic.

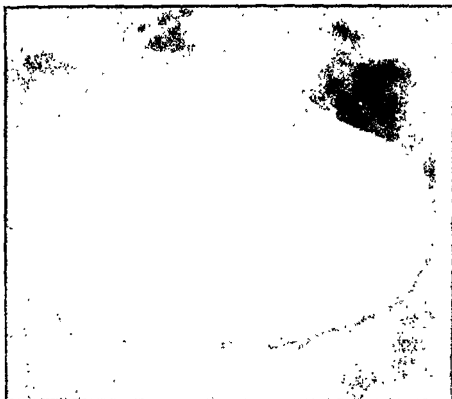


Fig. 3A.—Bladder of a multipara who has good urinary control, recumbent.



Fig. 3B.—Bladder of the same patient in the erect position. The base of the bladder sits lower in the pelvis; the internal sphincter is well supported.

push" of the bladder neck (internal sphincter) is a stimulus for the detrusor to contract. The contraction wave which starts at the bladder neck can be seen to spread symmetrically and bilaterally, first to the bladder base, then to the sides, and lastly to the dome of the bladder. The contraction of the detrusor causes a reciprocal opening of the internal sphincter and micturition proceeds.

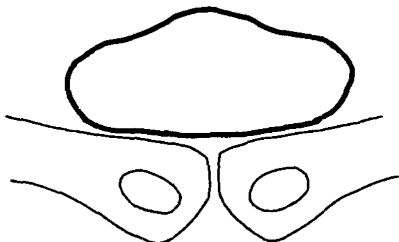


FIG. 4A.—Diagrammatic presentation of the steps in voluntary micturition: The bladder at rest.

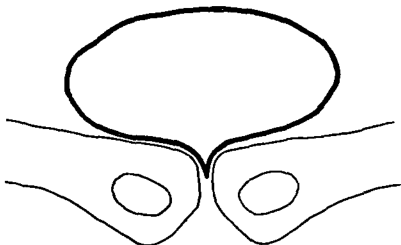


FIG. 4B.—Beginning of voluntary micturition Note how the internal sphincter has been pushed down.

The reflexes of micturition are thus initiated at will by a group of striated skeletal muscles which are somatically innervated. Of these, the muscles of the pelvic floor are the most important. The muscle which is particularly significant for micturition is the pubococcygeus which constitutes the anterior portion of the levator ani. The pubococcygeus is a paired skeletal muscle. It is in intimate contact with the bladder base and surrounds the urethra in the female. It is pierced by the urethra in much the same way that the esophagus pierces the thoracic diaphragm.

Deliberate interruption of the urinary stream is brought about not by the compression of the external urethral sphincter, as was taught in the past, but by

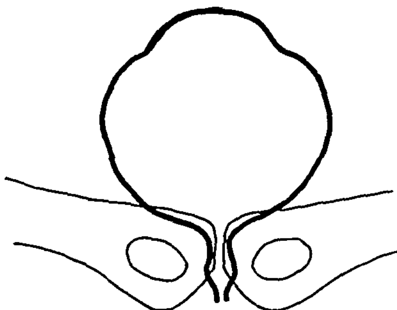


Fig. 4C.—The bladder during micturition: Note that the detrusor has contracted. The internal sphincter is open and the urinary stream proceeds.



Fig. 4D.—Bladder at rest in a nullipara with normal urinary control.



Fig. 4E.—Beginning of voluntary micturition. Note that the internal sphincter has been pushed down.



Fig. 4F.—Micturition: Note that the detrusor has contr...

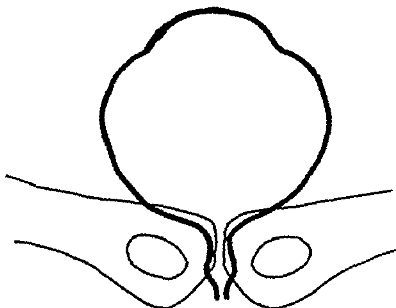


Fig. 4C.—The bladder during micturition: Note that the detrusor has contracted. The internal sphincter is open and the urinary stream proceeds.



Fig. 4D.—Bladder at rest in a nullipara with normal urinary control.

severity over a period of years and sometimes within a period of months. This is particularly apt to occur after rapid gain in weight. The increased severity of incontinence is due to the fact that the fibers of the unsupported internal sphincter bearing unaided the weight of the pelvic organs and coping with the forces of gravity become attenuated. On the fluoroscopic screen, the internal sphincter is now seen to have lost much of its snap and tonicity. The sphincter is more readily forced open, and in yielding to the force of stress opens more widely, permitting the escape of a large stream of urine (Fig. 10).

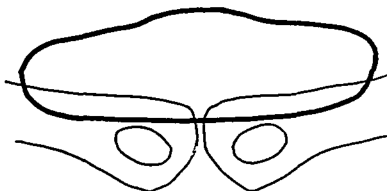


FIG. 5A.—Urinary stress incontinence: The outline of the bladder during recumbency.

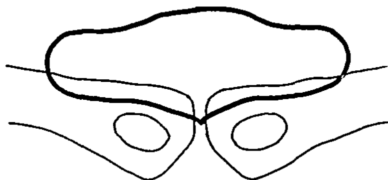


FIG. 5B.—Outline of the bladder in the erect position. Note the descent of the internal sphincter, and the pointed bladder base. The internal sphincter is now the most dependent point of the bladder.

In addition to the weakening of the internal sphincter, in severe cases of stress incontinence, progressive loss of tonicity of the pubococcygeus muscles adds to the severity of the symptoms, and the ability to stop the urinary stream promptly decreases. The internal sphincter sits low in the pelvis; it is readily pushed far down, and opens widely on sudden stress, thereby precipitating reflex contraction of the detrusor, so that true micturition ensues. It is for this reason that women with severe stress incontinence lose their entire bladder contents on stress.

Two factors, therefore, make stress incontinence worse: (1) the progressive weakening of the unsupported internal sphincter; and (2) the continued loss of tone of the pubococcygeus muscles. These factors must be kept in mind in the management of such cases.

a much larger maneuver which consists of the contraction of the entire levator ani, including the pubococcygeus.

On the fluoroscopic screen one can clearly see the bladder base to be sharply lifted up when micturition is deliberately stopped.

As soon as the bladder base is elevated, the internal sphincter snaps shut, and the stream is interrupted first at this point.

The pelvic floor muscles, i.e., the levator ani and the pubococcygeus, are thus seen to have a fourfold important physiologic function: (1) They initiate micturition at will; (2) they are utilized to stop the urinary stream; (3) they form a firm support for the internal sphincter and the bladder base; (4) they take up the added gravitational strain induced by the erect posture, which amounts to 10 to 12 mm. of mercury, together with any additional sharp increases in intra-abdominal pressure resulting from sudden exertion.

The mechanism of urinary control in normal women therefore consists of two parts. First, there is the internal sphincter which, in tonic contraction while the detrusor is relaxed, effectively shuts the bladder off, and, second, the pubococcygeus which firmly supports the internal sphincter and protects it against the effects of gravity and unusual stresses. The external urethral sphincter is not important in women. More than two thirds of the distal urethra can be excised without impairing urinary control.

PATHOLOGIC PHYSIOLOGY OF URINARY STRESS INCONTINENCE

If we now compare the urinary control mechanism in continent women with that of patients with stress incontinence, the reason why urine is lost will at once become apparent.

While recumbent the woman with stress incontinence has a bladder shape much like that of the continent multipara. The internal sphincter is normally shut off and shows no evidence of injury or deficiency (Figs. 5 to 10). If the fluoroscopic table is now elevated, the mere erect posture is seen to produce a characteristic change in the cystogram. This has been present in every case of incontinence examined to date and can, therefore, be said to be typical of stress incontinence.

While the bladder base now descends in the pelvis as a whole, it is specifically the region of the internal sphincter which drops even more and becomes the most dependent point of the bladder.

The bladder base now assumes the "pointed" appearance, characteristic of the bladder poised for micturition. Little further descent is now necessary to open the internal sphincter and to allow a jet of urine to escape. This is indeed what happens when the patient coughs.

Urinary stress incontinence is thus seen to be due to a specific weakness of the pubococcygeus muscle which permits the internal sphincter to herniate between its fibers. The lesion of stress incontinence is therefore not a general weakness of the bladder supports but a particular one, affecting especially the bladder neck. The internal sphincter, deprived of the support of the pubococcygeus which it needs in the erect posture to maintain continence, now depends entirely on its own integrity for urinary control.

It is a common clinical experience to see mild stress incontinence increase in

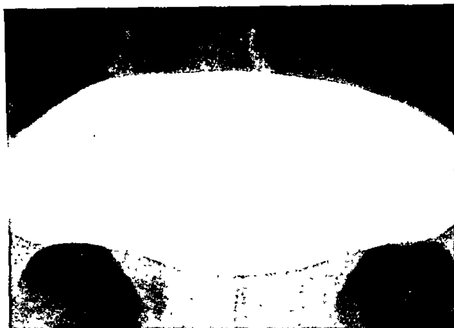


Fig. 7A.—Urinary stress incontinence: patient recumbent.



Fig. 7B.—Same patient, erect, not straining.

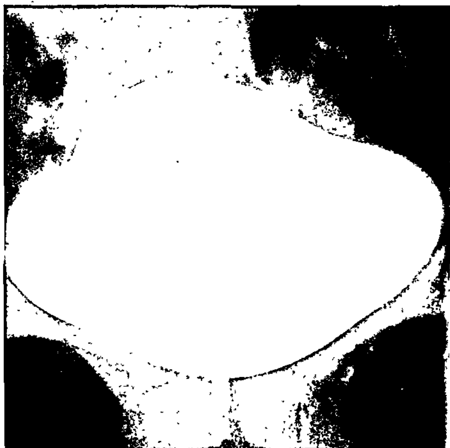


Fig. 6A.—Urinary stress incontinence: patient recumbent.



Fig. 6B.—Same patient in the erect position, not straining.



Fig. 9A.—Urinary stress incontinence: the patient is recumbent.

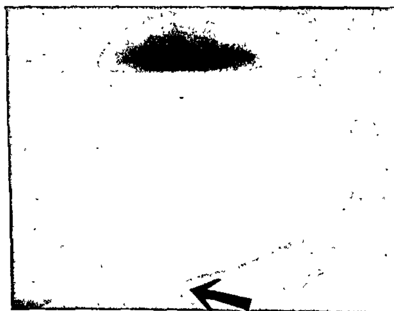
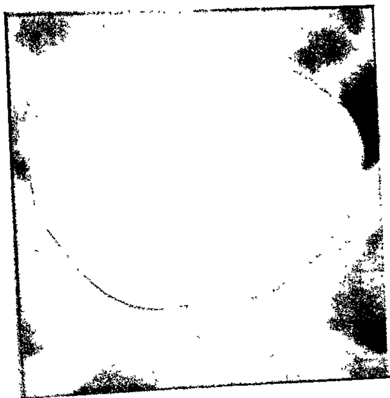


Fig. 9B.—Bladder of the same patient when erect, but not straining.



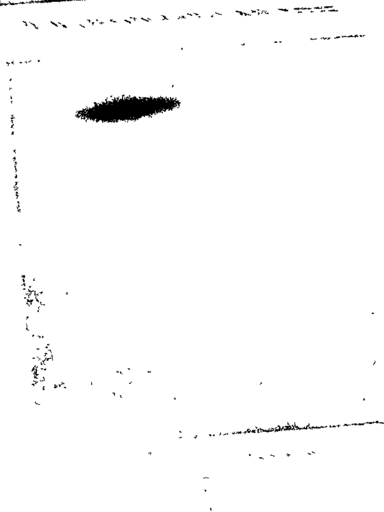




FIG. 10A.—Severe stress incontinence: the bladder at rest. Note that the internal sphincter is normally shut off.



FIG. 10B.—Bladder of the same patient during coughing. Note the marked descent of the bladder neck. The internal sphincter has been forced open and a large urinary stream escapes.



FIG. 10C.—Bladder of the same patient. Note that the cough has precipitated a detrusor contraction and true micturition proceeds.

Kegel's Perineometer, which presumes by means of exercises to increase the tonicity of the levator ani muscle, is thus based on sound physiologic principles. In the absence of this apparatus, improvement in tone can be gained by instructing the patients "to stop and to start" the urinary stream during each micturition. When they become conscious of the action of the pelvic floor muscles, patients can be taught to contract them for brief periods at intervals during the day. These exercises are more likely to be of value in the milder cases of incontinence.

The cause of urinary stress incontinence in young girls and nulliparous women has remained a mystery. These patients have excellent bladder supports in the recumbent and erect positions, and no abnormal mobility of the bladder neck can be demonstrated. Bladder fluoroscopy shows the weak urinary control in these patients to have a somewhat different etiology. In the supine position the bladder shadow appears to be normal in every way. On standing, however, there now appears a deep dimple in the region of the internal sphincter (Figs. 11 to 13). Occasionally the internal sphincter shows a "funnel-like" deformity. These patients then have a congenital weakness in the structure of the pubococcygeus in the midline through which the bladder neck herniates. When they cough, the unsupported internal sphincter is readily pushed open and a jet of urine can be seen to escape, demonstrating once more that a well supported bladder base and a bladder neck which is not abnormally mobile will not guarantee perfect continence, but that support of the internal sphincter is necessary to achieve this.

Urinary control and micturition make peculiar demands on the internal sphincter. The sphincter must have mobility to descend and rise freely in the pelvis with each micturition. On the other hand, it must have a firm support for urinary control. All the operations in use today to correct stress incontinence tend to elevate and to fix the internal sphincter. While such operations relieve the incontinence, they do not restore entirely normal mechanism of urinary control and actually interfere with physiologic micturition. Moreover, repeated attempts to press the internal sphincter downward for each micturition eventually break

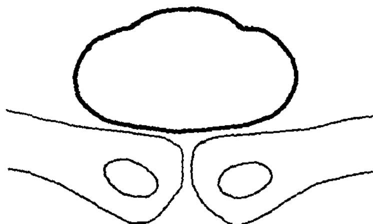


Fig. 11A.—Congenital stress incontinence: outline of the bladder during recumbency.

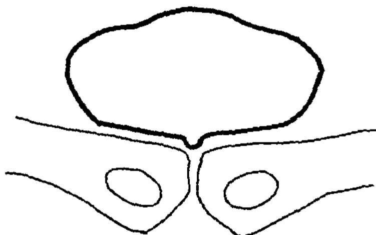


Fig. 11B.—Congenital stress incontinence. erect position; funneled bladder neck.

down the operative repair. Fascial slings become stretched and restraining sutures which hold the bladder neck up become attenuated. It is for these reasons that urinary continence tends to deteriorate eventually after a good immediate postoperative result.

The ideal operation which, while restoring continence would not interfere with the needs of the bladder neck for micturition, has as yet not been devised and until it is, it would be wise to turn our attention toward means of preventing distressing urinary incontinence and to treat the symptoms before they become severe.



Fig. 12A.—The bladder in congenital stress incontinence. The patient is in the recumbent position.

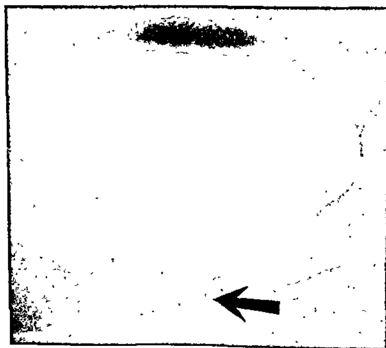


Fig. 12B—Bladder of the same patient in the erect position. Note the downward herniation of the internal sphincter.



FIG. 13A.—The bladder in congenital stress incontinence with the patient in the recumbent position.



FIG. 13B.—Same patient when erect. Note the pointed appearance of the bladder neck.

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Operative Technic for Stress Incontinence of Urine in the Female

WILLIAM T. KENNEDY, M.D.

The operative treatment for stress incontinence entails the restoration and maintenance of those structures which previously prevented urine escaping from the bladder.

Three axioms must be remembered:

(1) The true sphincter consists of the longitudinal and circular smooth muscles surrounding the inner two thirds of the urethra. This sphincter functions only when it is circular. Any distortion, either voluntary or involuntary, allows urine to escape from the bladder.

(2) The bladder and inner two thirds of the urethra are intimately enveloped in an endopelvic fascial sheath. The bladder and trigone lie loosely on the anterior vaginal wall, but the urethra and vaginal wall are intimately interwoven. The plane between the bladder and vaginal walls is loose connective tissue and allows the bladder to be easily separated from the wall. One constantly speaks of this as a cleavage plane.

(3) When the muscle of micturition contracts, it opens the true sphincter and allows urine to escape from the bladder. Conversely, when its opponent (levator urethrae, *transversus perinei,* and *bulbocavernosus*) muscles contract, they overcome the muscle of micturition and prevent the escape of urine.

Two procedures must be carried out:

(1) The urethra must be lengthened and replaced within the pelvis to restore the lost functions of the levator urethrae, the transversus perinei, and the bulbocavernosus muscles.

(2) A complicating cystocele must have the tear in the endopelvic fascia on the inferior bladder wall repaired to give the bladder permanent support.

OPERATION

(1) Expose the cervix, the anterior vaginal wall, and the urethra with a weighted vaginal speculum.

(2) Grasp the cervix with a tenaculum.

(3) Incise the anterior vaginal wall medially in front of the cervix to enter the loose connective tissue plane (the cleavage plane) lying between the bladder and the wall (Fig. 1).

(4) Dissect the bladder bluntly from the vaginal wall with a sponge forceps, carefully following the cleavage plane up to the internal meatus of the urethra and from one ramus to the other.

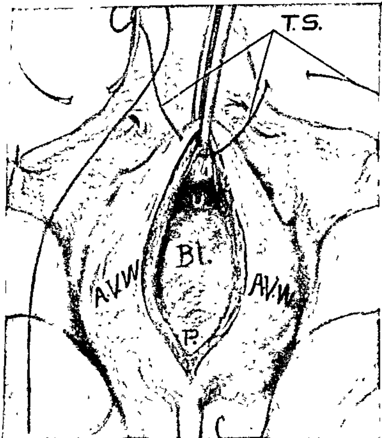


Fig. 1.—The anterior vaginal wall, the bladder, and the cervix are exposed. (AVW) anterior vaginal wall; (Bl) bladder; (C) cervix; (P) plane of cleavage; (TS) traction suture to hold the anterior end of the incised vaginal wall.

Between the anterior vaginal wall and the bladder lies a network of alveolar tissue which loosely holds them together and in which run the blood vessels. This tissue is easily broken, hence it is termed the *plane of cleavage*. It is easily entered at (P) and followed up the midline with a sponge forceps to within 2 cm. of the external meatus of the urethra. The anterior vaginal wall is now incised as shown.

For maximal results in treating incontinence one must correct any cystocele which may be present.

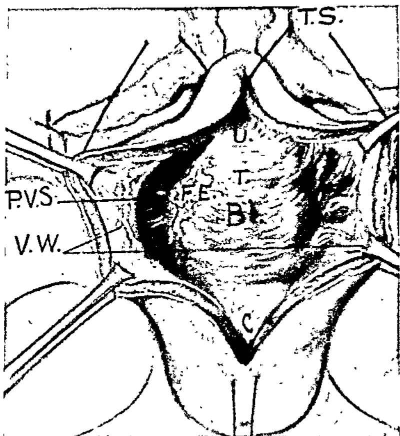


Fig. 2.—Further separation of the bladder and urethra. (PVS) paravesical space; (FE) fascia endopelvina; (U) urethra; (T) trigone; (VW) vaginal wall; (Bl) bladder; (C) cervix; (TS) traction suture.

The *fascia endopelvina* envelopes the bladder and inner two thirds of the urethra. Frequently by trauma this fascia covering the inferior bladder floor, the trigone, and the inner two thirds of the urethra, is stretched or damaged, leaving the exposed muscle to herniate.

The bladder, displaced toward the external os of the cervix, is freed from it.

The *plane of cleavage* is followed within the pelvis to enter PVS, the paravesical space, and then is extended completely to free the urethra and bladder laterally (but not superiorly) from the pubic ramus. The dissection is repeated on the opposite side.

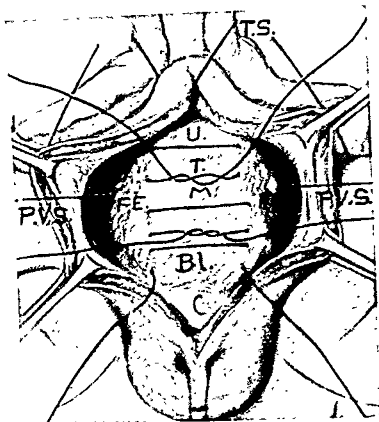


Fig. 3 –Mattress sutures are placed to plicate the herniated tissue of the urethra, trigone, and bladder. (PVS) paravesical space; (T) trigone; (U) urethra; (FE) fascia endopelvina; (Bl) bladder; (C) cervix; (TS) traction suture.

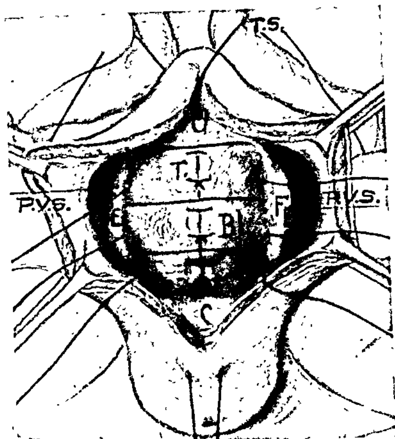


Fig. 4.–Replication of the bladder trigone and urethra approximates the margin of the damaged fascia endopelvina. (PVS) paravesical space; (U) urethra; (T) trigone; (FE) fascia endopelvina; (Bl) bladder; (TS) traction suture.

(5) Continue the median incision of the wall as high as the dissection.

(6) Remove the urethra from the vaginal wall to a point about 1 cm. from the external meatus.

(7) Bluntly dissect, with a sponge forceps (along the cleavage plane), the bladder from the tissue covering the ramus. Adhesions of the bladder and urethra to the ramus which may be causing permanent incontinence will have to be excised. Carry the dissection up into the paravesical space.

(8) Repeat the dissection on the opposite side.

(9) Separate the urethra laterally completely from the ramus.

(10) Do not disturb any superior support of the urethra to the symphysis.

(11) Ligate all actively bleeding vessels.

(12) Push the cervix deep into the vagina.

(Steps 13-18 constitute the procedures necessary to restore the floor of the bladder, to attach the bladder to the cervix, *to lengthen the urethra,* to thicken its inferior wall, and to tighten the true sphincter of smooth muscle.)

In all plastic procedures carefully remove all fibrin and blood clot before tying the sutures.

(13) Plicate the bladder wall in the median line with interrupted mattress sutures of No. 00 catgut placed about 1 cm. apart.

(14) Identify the ragged margin of the fascia endopelvina which should be about 1 cm. lateral on either side of the tied sutures.

(15) Approximate the opposite sides of this fascia endopelvina in the median line by interrupted mattress No. 00 catgut sutures placed about 1 cm. apart. (This double plication serves two purposes: (a) it restores a normal floor to the base of the bladder, and (b) it makes a median splint beneath urethra and bladder. thus giving the urethra increased length and a tighter true sphincter.)

(16) By a single suture attach the innermost end of the fascia endopelvina tissue of the bladder to the cervix anteriorly, about 2 cm. from the internal os.

(17) Estimate the amount of excess vaginal wall present and excise the unnecessary tissue.

(18) Beginning at the cervix, close the vaginal wall medially with No. 00 catgut sutures.

(Steps 19-23 are essential to restore the lost function of the levator urethrae muscles by replacing them as nearly as possible to their pre-damaged position where they normally kept the urethra high within the pelvis. Here they exert the maximum force *to lift* the urethra into the pelvis.)

(19) Identify the dimple on one side, then grasp the vaginal wall with an Allis clamp, having one jaw in the dimple. Be sure that traction on the clamp pulls the levator muscle; if it does not, move the clamp higher until the end of this levator is stretched with traction.

(20) Pass a No. 1 catgut suture in through this tissue above the clamp.

(21) Repeat procedure 18 on the other side and pass the "in" end of the catgut out through this tissue above the clamp.

(22) Pull on the ends of the catgut to approximate the dimples.

(23) Estimate the excess vaginal wall and liberally excise the vaginal wall so that when healing takes place the dimples will be held quite closely together.

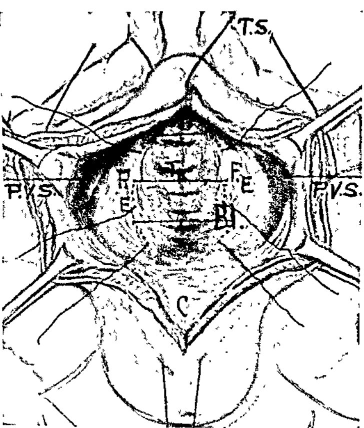


Fig. 5—Replication of the fascia endopelvina to restore normal functioning support beneath the urethra, trigone, and bladder. (PVS) paravesical space; (FE) fascia endopelvina; (U) urethra; (T) trigone; (Bl) bladder; (C) cervix.

Notes: (1) the urethra and trigone now have a splint of original tissue beneath them. (2) The circular smooth muscle, the true sphincter, surrounding the inner two thirds of the urethra is shortened by pressure from without and can again function normally. (3) The urethra has been restored to its original length; one of the writer's axioms for continence. (4) The urethra and trigone now have no lateral attachments, to distort the circular true sphincter.

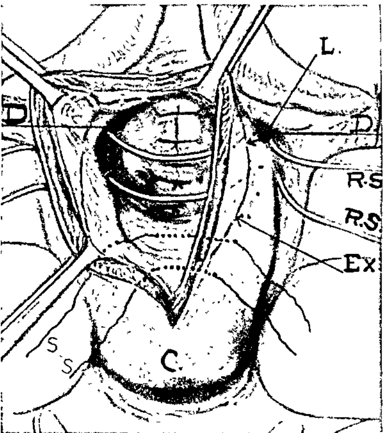


Fig. 6.—Steps necessary for efficient rehabilitation of the *levator urethrae muscles.* (D) dimple, the vaginal point above which the levator urethrae insertion is attached; (L) the distance (about 1 cm.) *from the dimple to the edge* of the remaining vaginal wall after the redundant wall has been excised; (Ex) line of excision of the redundant vaginal wall; (RS) reinforcing suture, 0 plain catgut; (SS) are 00 plain catgut sutures to close the anterior vaginal wall.

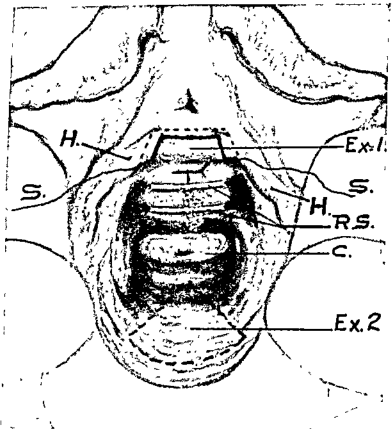


FIG. 7.–Approach to restore the function of the fibers of the transversus perinei and bulbocavernosus muscles. These muscles assist the levator urethrae to lift the urethra back within the pelvis after urination has been completed. (HH) the stretched suburethral portion of the hymen; (Ex. 1) area excised to approach functioning fibers of the transversus perinei (profundus) muscle; (SS) suture placed to approximate excised ends of muscle; (RS) reinforcing sutures; (C) cervix.

(Ex. 2) area of mucosa of vaginal wall and fourchette removed to correct rectocele, sphincter ani sheath damage, levator dysfunction, damage to Colles' fascia, and to restore the bulbocavernosus ends into the reconstructed perineum.

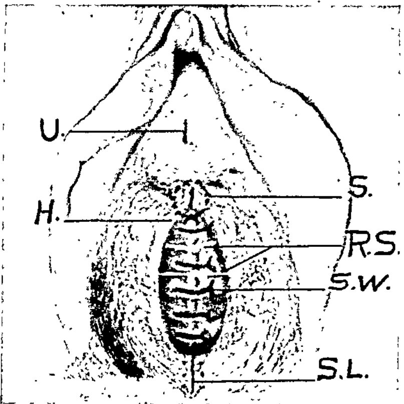


FIG. 8.–The completed procedure. (U) external urethral meatus; (S) suture restoring transversus perinei muscle; (RS) reinforcing sutures to approximate insertions of the levator urethrae muscle; (SL) suture line of perineal closure; (SW) interrupted sutures closing the vaginal wall; (H) hymen.

The insertions of the *levator urethrae* are held close beside the urethra by the two reinforcing sutures (RS). The *transversus perinei muscle fibers* of this region are restored to almost normal function by suture (S). The *bulbocavernosus muscle ends* have been approximated in the midline of the perineal body in the suture line (SL).

A little experience is necessary to estimate the optimum amount of tissue to leave here.

(Step 24 describes the reconstruction of the transversus perinei (urethral portion) to enable it to exert its maximum force *to hold* the urethra in the pelvis.) The transversus perinei muscle with its fascial sheath is probably the most immobilizing support of the urethra.

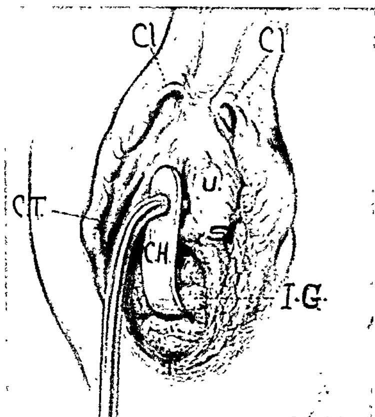


Fig. 9.—A vitallium retention urethral catheter held in place by a vitallium holder kept in the vagina by light iodoform packing. (U) urethra; (S) transversus perinei suture; (CT) catheter; (CH) catheter holder; (IG) iodoform gauze.

(24) Excise a wedge from the "curtain" in the midline. Determine the optimum amount of tissue to leave so that this muscle may possess maximum function. Approximate the remaining ends with one or two interrupted No. 0 catgut sutures.

(Step 25 describes the restoration of the bulbocavernosus muscle to give it its maximum force *to push* the urethra back into the pelvis.)

(25) The bulbocavernosus muscle can be shortened to become most effective only by repairing the perineum. To do this, the ends of this muscle must be exposed during the perineal dissection and then approximated in the midline by No. 0 catgut sutures.

(26) After a careful reconstruction of the tissues as indicated it is important that manipulation or stretching of the urethra, vaginal bladder wall, and perineum or vaginal orifice should be avoided. Catheterization frequently damages the

plastic repairs. To avoid this the writer uses a self-retaining vitallium catheter which can be left in place for four or five days.

(27) Irrigate the catheter and bladder occasionally if indicated. The writer rarely does this.

(28) Clamp the catheter and fasten the clamp to a waist belt when the patient gets out of bed.

(29) Remove the catheter and holder about the sixth postoperative day.

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The Vaginal Approach in the Surgical Treatment of Stress Incontinence

With Special Reference to Certain Factors Necessary to the Cure of this Condition

INGLIS F. FROST, M.D.

KELLY IN HIS *Practice of Gynecology*, published in 1928, stated: "The list of operations devised to overcome incontinence is legion, mostly unsuccessful but occasionally, temporarily at least, affording some control."

An editorial footnote appearing in the *Year Book of Obstetrics and Gynecology, 1950* on an operation for stress incontinence states: "The appearance of new operations for stress incontinence year after year indicates that no one is entirely satisfactory. Generally it is best to attempt to cure these patients by the Kelly operation. If this fails one must resort to more extensive operations, preferably through the vagina, with or without fascial strips."

These two statements, made within a period of 22 years, are strikingly similar, and the natural conclusion would indicate that pelvic surgeons are still seeking an ideal operation for the cure of stress incontinence.

An operation of this type would be impossible to achieve on account of the variability of the causes and the degree of damage found in this condition.

While it is true that many operations which have been devised in the past few years have proved successful, the incidence of operative failures still remains high. Statistics show either a partial or total failure of about 10 to 20 per cent.

Despite the fact that lack of success in the cure of many patients is still a common occurrence, decided progress has been made toward a better understanding of the underlying causes of stress incontinence and anatomic relations of the urethra and bladder. This has led to improvement in operative technic and the end-results of today are vastly superior to those of 20 years ago.

The largest percentage of failures occurs in the primary operative group of patients. Many of these need several operative attempts before a cure is effected. If it were possible to "cure the first case first" there would be less necessity for the more radical type of surgery.

The reoperative case presents added problems; the original cleavage planes become obliterated and the formation of scar tissue makes for difficult surgery. It is in this type of case that the operator is forced to seek extra support for the urethra and bladder by the use of muscle or fascial slings.

There are numerous reasons why the primary operation fails; many of these should and could be avoided.

The fact that women vary greatly in muscular tone of the periurethral and perivaginal muscle tissue is one reason for accountable failures. All gynecologists have had the experience of performing a surgically correct plastic operation, only to be disappointed in the end-result.

Kegel has demonstrated that many patients need reactivation and regeneration

of their urethral and vaginal muscles prior to operation; otherwise failure may occur.

A further cause of failure is either a neglect to suture the vesical neck of the bladder, or, if sutured, to place the Kelly stitch too far distant from the vesical sphincter to be of value. The use of a single suture at the vesical neck is more often doomed to failure than success. One suture in this region many times fails to reduce the caliber of the urethra or vesical sphincter; also, it is inadequate in restoring the urethra to its normal posterior position.

Failure may be the result of an improper selection of operation for the type of incontinence, as, for example, it may be better judgment to use a sling type of operation primarily, rather than attempt to cure the patient by plastic repair alone.

It is probable that the largest number of failures is due to a lack of knowledge and understanding of the proper cleavage planes of the vagina, urethra, and bladder, with resultant failure to use these planes to the best advantage in securing the maximum support and position of the urethra and bladder.

The patient who presents herself with a history of a lack of urinary control should have a thorough gynecologic, urologic, and neurologic examination. This examination should differentiate the nonoperative type of case from the operative. It should be kept in mind that many conditions may cause dribbling of urine which is not true stress incontinence.

Urethritis, trigonitis, urethral polyps, and urethral caruncles may cause dribbling but these are local conditions which belong in the realm of the urologist.

Other conditions causing incontinence but not in the operative category would be the neurologic bladder, cystologic infections, hematologic bladder conditions, and intrapelvic tumors.

Cases of stress incontinence requiring operation are generally the aftermath of child-bearing, but are often associated with such contributing causes as congenitally weak tissues, poor muscle tone, and postmenopausal tissue atrophy.

To effect a cure in stress incontinence one must possess a thorough knowledge of the histologic and anatomic relations of the vagina, urethra, and bladder and their muscular correlations; also their relation to the surrounding supportive voluntary pelvic muscles.

In general, most observers agree on the musculature of the bladder and urethra but there are differences of opinion as to the arrangements of these muscles, especially those of the urethra and their mode of action.

Kennedy describes the muscle which allows the urine to escape from the bladder as a striated muscle and calls it the "muscle of micturition." It is, according to Kennedy, "an oblique purse-string muscle which obliquely surrounds the urethra and has a double origin of which each is loosely attached to the periosteum of the anterior surface of the ramus of the pubis. From these origins the muscle crosses over the urethra and enters its wall; it then travels posteriorly and obliquely and mingles with the smooth circular and longitudinal muscle fibers of the urethra and finally becomes inserted by two fingers into the musculature of the trigone.

"Opposing this muscle of micturition is the true sphincter of the urethra. This is a smooth tissue muscle which surrounds the inner two thirds of the urethra.

It is made up of both circular and longitudinal fibers, the longitudinal fibers being to the inner side of the circular fibers."

Kennedy states: "When the muscle of micturition contracts, it changes its contour from an oblique to a circular shape and in so doing the urethra becomes distorted, causing the circular true sphincter to assume an elliptical shape. When this takes place the inferior wall of the urethra, at the region of the inner third, moves forward until it is directly under the middle third of the superior wall. *The trigone then moves to a position under the superior wall of the inner third* and the urine is thus allowed to escape from the bladder.

"The surgical procedure necessary to correct this condition must be to lengthen the urethra and replace it as far within and as high in the pelvis as possible. This will allow the true sphincter of the urethra to again assume its normal circular shape and the muscle of micturition to regain its oblique contour when it is in relaxation."

According to Kennedy, "The muscles which restore to the true sphincter its original control are the levator ani muscles which, being in close approximation to the urethra near the junction of its inner and middle third, lift its lateral walls up and within the pelvis. The bulbocavernosus muscle aids by compressing downward and inward the outer third or glandular portion of the urethra and the deep transversus perinei muscles lend support to the urethra at the junction of its *outer and middle third.*

"At the time of voiding these muscles relax and by so doing allow the muscle of micturition to draw the urethra into its voiding state; consequently any operative procedure for the correction of incontinence must take into account the actions of these muscles and restore them so that they may regain and maintain their function."

Ricci recently published a histologic study of the urethra, based on a study of 21 urethras ranging in ages from a four months fetus to a 77 year old woman.

Anatomically, Ricci divides the urethra into three parts—upper, middle, and lower thirds. He states: "The musculature of the upper third is in reality an extension of the muscle of the lower portion of the bladder. There are three layers of muscle at this portion of the bladder and urethra, an outer longitudinal, a middle circular, and an inner longitudinal. The middle muscle is more heavily developed than either the outer or inner longitudinal muscle, while the inner at times may be absent altogether. The middle circular muscle encircles the lower portion of the bladder and is very prominent at the internal urethral orifice and upper portion of the urethra. Posteriorly, this circular muscle fuses with the fibromuscular trigone and urethrovaginal wall. The middle third of the urethra has an outer muscle bundle which is striated in character and circular surrounding this part of the urethra and tapers off at the ends. The middle urethra also has an *inner layer of involuntary muscle. The lower third of the urethra is made* up mostly of fibrous tissue. The whole urethra is composed of an inner layer of mucous membrane, next to it a substantia propria with elastic fibers and blood vessels, the lower end being extremely fibrous in character. At the urethral orifice there are glands and Skene's ducts."

These two anatomic studies of the musculature of the urethra and bladder are at variance. Kennedy's concept of the "muscle of micturition" may be correct and

could be the answer to the cause of stress incontinence, but, whether it is or not, one factor is certain—the importance of "putting the internal urethral meatus as far back in the pelvis as possible," as Kennedy has stated.

In 1931 Goff published his treatise on the perivaginal fascia in a nullipara and showed by histologic sections that there is no tissue between the walls of the vagina, urethra, bladder, and rectum which can be called fascia as the term is generally understood. He further demonstrated that there is an absence of areolar fascia between the urethra and the anterior wall of the vagina, but there is a loose areolar fascia, or tissue, between the anterior vaginal wall and the bladder and also an areolar fascia between the posterior vaginal wall and the rectum. "These two loose areolar fascias unite on either side of the vagina to form the perivaginal areolar fascia."

This perivaginal areolar tissue (fascia) continues upward on either side of the vagina and becomes continuous with the areolar endopelvinia connective tissue on either side of the urethra and bladder and passes under the true ligaments of the bladder and to the inner side of the levator muscles.

The work of Goff has been corroborated by many histologists and gynecologists. Ricci bears out Goff's findings and points out the definiteness of the fusion of the urethra to the anterior vaginal wall. He states: "This fusion is from the base of the trigone to the external urethral orifice. It forms a compact urethrovaginal wall completely integrated into one solid structure by interweaving connective tissue and elastica. Interweaving is so intimate that it is difficult to distinguish the muscle component of the vagina from that of the urethra. The upper urethra and the trigonal area of the bladder are surrounded by a muscular coat of variable arrangement. The trigonal area of the bladder and upper vagina remain tightly fused. The cleavage plane between the bladder and vagina is packed with loose areolar tissue. The lowermost part of the vesico-uterine fold usually reaches the level of a plane passed between the interurethral ridge and upper vagina at the fornix. Rarely it extends beneath the trigone as far as the internal urethral orifice."

This loose areolar fascia, or areolar connective tissue as it should properly be termed, forms the natural planes of cleavage which should be followed in any approach in vaginal plastic surgery and in any operations for stress incontinence by the vaginal route.

According to Barnes, stress incontinence may be the result of two separate factors or it may be the result of a combining of these factors. "These may be either an increase in urinary expulsive force or a decrease in urethral resistance."

Barnes states: "When the bladder is at rest, the internal sphincter is firmly closed, but is not in a state of continuous contraction. If from this closed state there is a gradual distention, a contractive force is exerted in direct proportion to the amount of distention. Naturally there is no contraction if there is no distention by cystic fluid, but immediately the musculature around the trigone tends to open the internal urethra, the voluntary muscles tend to close the urethra. When this mechanism fails to function, we have stress incontinence."

Barnes continues: "It is easy to understand that any increased force exerted by such acts as sneezing, coughing, or an increase in intra-abdominal pressure could add intracystic pressure and if the internal sphincter is at fault the external volun-

tary sphincter is immediately brought into action to try to control the loss of urine." This, Barnes says, may be possible when the patient is in a recumbent or resting position but if the condition progresses and the patient is unable to exert her voluntary control rapidly enough to control her urine under stress conditions she becomes incontinent.

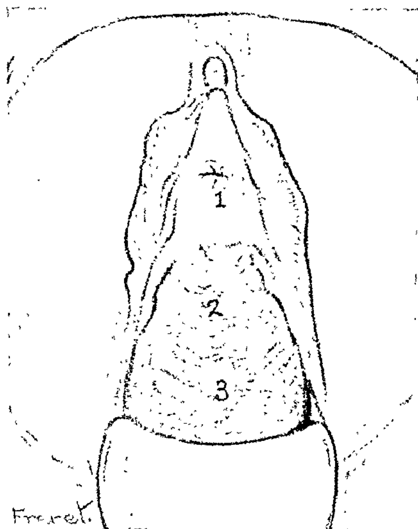


FIG. 1—(1) Urethra, (2) urethrocele, (3) cystocele.

The work of Kegel in demonstrating the necessity of vaginal exercises to re-educate and strengthen the perineal and periurethral muscles in stress incontinence must form an important part in the cure of this condition.

Kegel believes that, "instead of poor tissues causing poor function, the viewpoint is that faulty development of awareness of function and co-ordination, is the cause of poor tissues or atrophy of disuse," and to overcome this condition he advocates the use of a perineometer to exercise and reactivate the perineal and periurethral muscles.

Kegel states that 70 per cent of women possess good vaginal function and tone, while 30 per cent, regardless of birth trauma, have poor tone. This fact would explain many of the poor results obtained in stress incontinence operations and the need of increasing perineal muscle resistance either prior to or after operation.

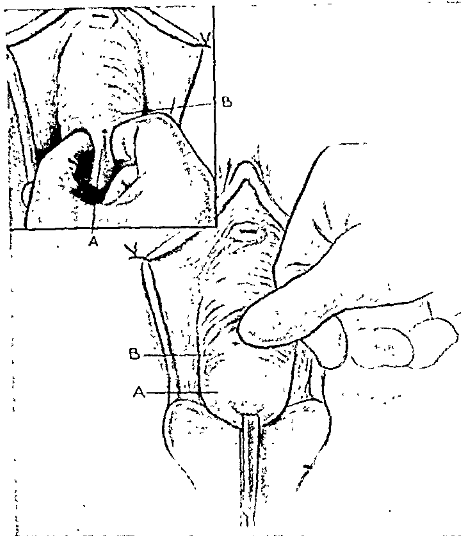


Fig. 2.—The smooth surface (A) indicates a portion of the vaginal wall completely fused with the cervix. The area marked (B), showing the vaginal rugae, indicates the beginning of the cleavage plane which separates the vaginal wall from the anterior surface of the cervix. This wall is massaged upward toward the urethra with swings of the thumb.

Insert: The entire thickness of the vaginal wall above the area is grasped with the fingers and elevated. This area is rubbed between the fingers to "increase" separation.

(Ricci, J. V., Thom, C. H., and Kron, W. L.: Am. J. Surg., 76:354, 1948.)

The problem, according to Kegel, "lies almost entirely with the pubococcygeus muscle and its relation to the bladder, mid-portion of the vagina, and partially the rectum. If the patient fails in the development of this muscle the results are poor."

As Kennedy has demonstrated, the levator ani muscle, the bulbocavernosus, and

the transversus perinei profunda play important parts in the control of the sphincter action of the urethra. Their revitalization and operative readjustment are important factors in the cure of stress incontinence.

If the Kegel perineometer is used as an indicator prior to vaginal exercise and prior to vaginal plastic surgery, it will be noted that few patients can raise the indicator to beyond 5 or 10 mm. Hg. Following an operation this is hardly improved, indicating that while the operation may be surgically perfect there still remains a loss of tone and function of the periurethral and perivaginal muscles.

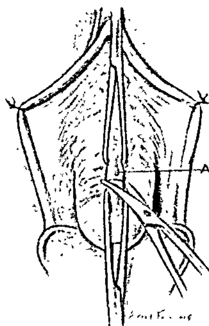


Fig. 3.—The doubled thickness of the entire vaginal wall is grasped between two Allis clamps and held taut, it is cut transversely with one stroke of the scissors. This incision properly executed at the proper level leads directly into the anterior avascular space or cleavage plane. (Ricci, J. V., Thom, C. H., and Kron, W. L.: *Am. J. Surg.*, 76:353, 1948.)

This is mostly true in the postmenopausal group of patients, where atrophy and loss of tone of the vaginal and urethral muscles are marked and where reactivating exercises are necessary to obtain a satisfactory cure.

We find that many of our patients learn with difficulty to contract the vaginal muscles postoperatively, if they have not been taught prior to operation. A simple method of teaching these patients is to place one finger in the anus and another in the vagina and ask them to squeeze on their anal sphincter. By this method they quickly learn how to contract the vaginal muscles.

In the earlier years of gynecology the term urethrocele was used only in referring to a sacculated urethra, sinus of the urethra, or a urethral diverticulum. Recently the term has been used more generally to describe a definite hernial protrusion of the urethra in the region of the vesical neck of the bladder.

Graves stated: "The descent of the bladder may include the urethra and

when this takes place the condition is termed urethrocele. Urethrocele is usually only an incidental part of the process of cystocele but may occur alone."

Curtis contended that urethrocele is a prolapse caused by a laceration of the vesicovaginal fascia, causing the urethra to rotate downward around the pubic bone, and that relaxation of the vesical sphincter is commonly present.

If the vesical sphincter is the normal junction between the urethra and the bladder, it should be the dividing line between a urethrocele and a cystocele. When the vesical sphincter is relaxed there is a merging of these conditions, thereby causing a combined cysto-urethrocele and shortened urethra.

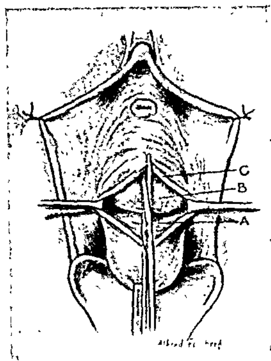


Fig. 4.—Exposure of the avascular areolar cleavage plane or space. At mid-point of the initial transverse incision of the entire thickness of the vaginal wall, a longitudinal incision is begun and continued upward, again including the entire thickness of the vaginal wall. This incision ends at the point of fusion between the vagina and urethra. (A) indicates the surface of the cervix; (B) free bladder musculature; (C) entire thickness of the vaginal wall.
(Ricci, J. F., Thom, C. H., and Kron, W. L.: *Am. J. Surg.*, 76:353, 1948.)

The position of the urethra in relation to the bladder, according to Reich et al., should normally be a 45 to 50 degree angle. In the presence of a cysto-urethrocele this angle increases to a 90 degree angle rotation.

The length of the normal urethra, according to Piersol, is about 4 cm. to 4.5 cm., but in many patients with a cysto-urethrocele and incontinence this will be found to be shortened. In any operation for stress incontinence the angle and the length of the urethra must be restored to the normal.

The incontinent patient invariably has a relaxed vesical sphincter and a shortened urethra but this condition is also found frequently in patients with a urethrocele and cystocele but without incontinence. This fact naturally leads us to the conclusion that a relaxed vesical sphincter is not the sole cause of stress incontinence and that other factors must play an important part in producing

this condition. The mere tightening of the vesical neck by a single Kelly suture is more often unsuccessful than successful, as it neither restores the normal angle nor lengthens the urethra.

In observing the bladder of a patient with a cystocele and urethrocele it will be noted that the base of the bladder is attenuated and thinned out at its central portion but laterally on either sides the walls are firm and smooth. It is thought

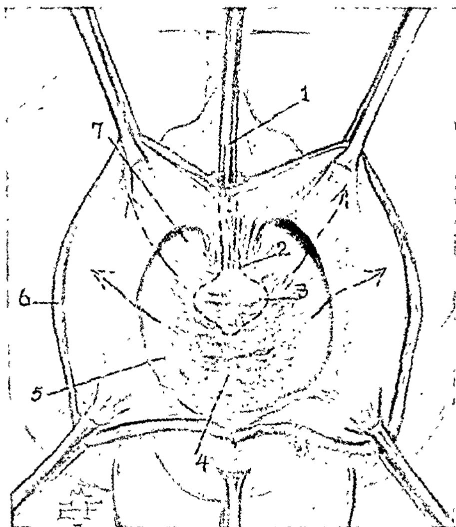


Fig. 5—(1) Foley catheter, No. 12, (2) vesical neck of the bladder: *note the shortened urethra;* (3) tip of the Foley catheter at the site of the urethrocele; (4) cystocele: *note the thinned-out portion of the bladder wall,* (5) smooth capsule of the bladder wall; (6) anterior vaginal wall; (7) area of dissection under the pubic rami.

by many observers that this is due to a rupture of the bladder muscle fibers during childbirth. Others feel that it is probably due to the bulging of the base of the bladder with thinning of its walls because of its unsupported position in the cystocele. Laterally on either side where the bladder wall is firm and smooth there is better support by the vaginal wall and the areolar connective tissue still remains intact.

Anterior vaginal wall plastic surgery has undergone a gradual evolution in the past few years. Formerly more attention was paid to the so-called fascial support for the cystocele and urethrocele by splitting the anterior vaginal wall flaps and suturing their innermost part across and in front of the bladder and urethra.

Goff has shown the fallacy of using any part of the anterior vaginal wall as a fascial support and has shown by histologic sections that the vaginal wall in

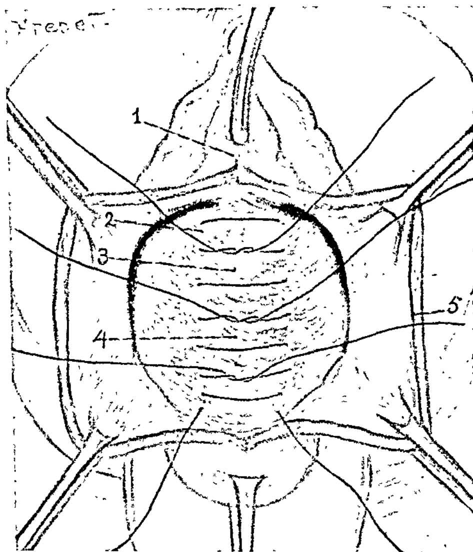


Fig. 6.—(1) The incision is carried to within 1.5 cm. of the external urethral meatus; (2) the first suture is placed high in the urethra, (3) the second suture is placed in the region of the vesical neck; (4) remaining mattress sutures are placed in the region of the cystocele; (5) the anterior vaginal wall.

itself "is made up of stratified squamous epithelium and a fibro-elastic tunica propia which forms the mucosa. Above this is the muscular coat of the vagina composed of smooth muscle fibers, both circular and longitudinal, and above this is the thin areolar connective tissue separating the vaginal wall from the bladder."

Gynecologists, realizing the absence and lack of the necessary fascial support to be found in the anterior vaginal wall, now prefer to plicate the bladder and

urethra to reduce the cystocele and urethrocele. Dependence on the anterior vaginal wall for support of these tissues has proved to be inadequate.

The treatment of stress incontinence, urethrocele, and cystocele must be approached with the over-all anatomic picture in mind, as damage to the urethra and bladder not only impairs the anatomic relationship of these organs, but their function as well.

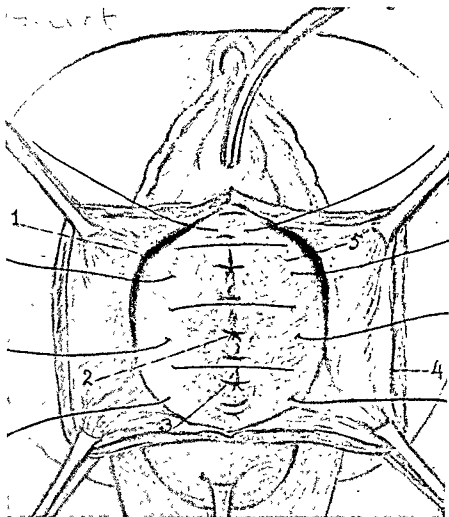


FIG. 7.—(1) Space under the pubic rami with free mobilization of the bladder; (2) first suture placed high in the urethra; (3) second suture is placed in the region of the vesical neck; (4) remaining mattress sutures are placed in the region of the cystocele; (5) anterior vaginal wall.

The first step in the treatment of stress incontinence is the thorough mobilization of the base of the bladder and the urethra laterally, keeping in mind that the urethra fuses anteriorly with the anterior vaginal wall. Any separation here may cause severe bleeding. The mobilization of the base of the bladder includes separation from the anterior vaginal wall up to the fusion point of the urethra with the anterior vaginal wall, separation of bladder from the cervix as far as

the uterovesical fold, laterally on either side until the smooth wall of the musculature of the bladder is visualized and mobilized enough for suturing without tension and on each side of the urethra under the pubic rami.

All of this free mobilization of the bladder and urethra must be carried out by adhering strictly to the cleavage planes; otherwise there may be injury to the bladder and urethra with ensuing hemorrhage.

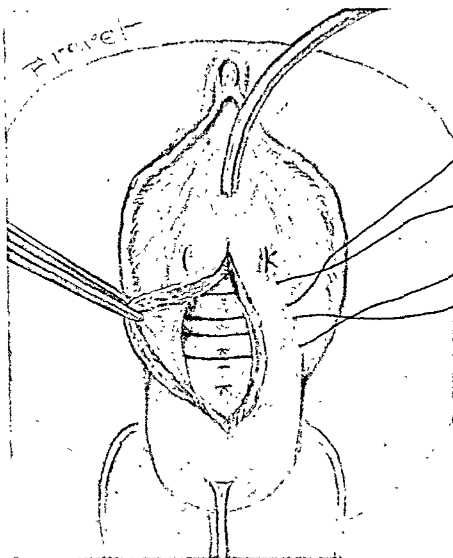


FIG. 8.—Sutures tied in the bladder wall, three mattress sutures through the entire thickness of the anterior vaginal wall with interrupted sutures.

TECHNIC

The cervix is grasped with a tenaculum and pulled downward, thus placing the anterior wall on tension just above the point of fusion of the anterior vaginal wall and the cervix. The anterior vaginal wall is grasped between the thumb and the forefinger and the vaginal wall is massaged and pushed upward, thus

releasing the lower portion of the bladder and accentuating the cleavage plane at this point. Two Allis clamps are now placed on the vaginal wall, including its whole thickness; the lower one about ¾ inch above the external os and the upper one about ½ inch above the lower clamp. Using a pair of straight scissors, and with the Allis clamps on the stretch, a transverse incision is made between them. This should include the whole thickness of the anterior vaginal wall and will open the avascular space just below the bladder.

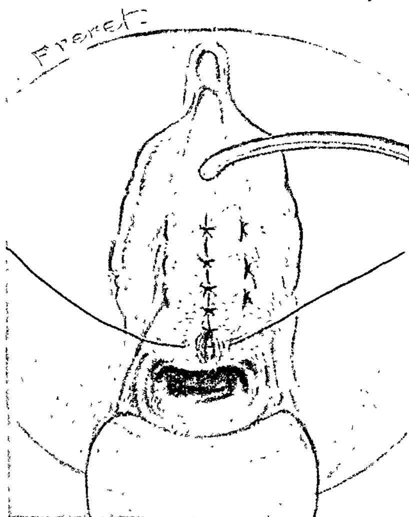


FIG. 9—Mattress sutures tied, closing space between the plicated bladder and the anterior vaginal wall. The anterior vaginal wall is closed with interrupted sutures.

The initial scissors incision is enlarged laterally on either side slightly and the Allis clamps are removed and placed laterally on either side of the incision. If one has entered the proper cleavage plane, marked by a pocket formation of whitish color, the scissors, or preferably a Simms clamp, may be passed upward freely between the bladder and the anterior vaginal wall. The vaginal wall is now bisected through its entire thickness and the bladder is separated from

the vaginal wall as one proceeds. This whole separation of the bladder from the anterior vaginal wall should be made in the cleavage plane where there will be a minimal amount of bleeding.

The initial incision dividing the vaginal wall is carried to within 1.5 cm. of the external urinary meatus.

By blunt dissection, with a gauze-covered finger, the bladder is now thoroughly separated from the anterior vaginal wall from the cervical surface to the vesico-uterine peritoneal fold and laterally on either side until the smooth musculature of the bladder is visualized. Here it is freely mobilized for the placing of invaginating sutures. This line of cleavage is now carried upward

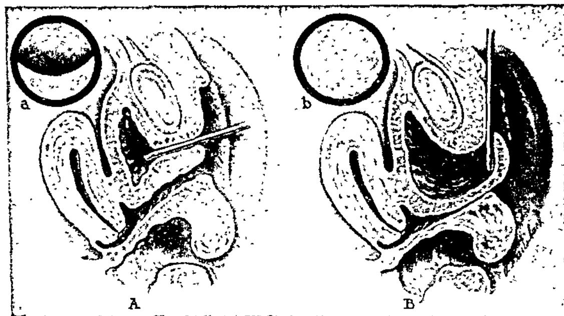


Fig. 10.—(A) Normal bladder and urethra. The catheter describes a 45 to 50 degree angle with the catheter horizontal on insertion. (a) Cystoscopic view obtained in normal urethrovesical anatomic status and relationship.

(B) Cystocele and urethrocele, illustrating the anatomic departure from the normal. The inserted catheter assumes a 90 degree angle with the horizontal. (b) Cystoscopic view obtained in cysto-urethrocele.

(Reich, W. J., Wilkey, J. L., and Silverman, H. E.: *Am. J. Surg.*, 70:341, 1945.)

under the symphysis on either side of the urethra, freeing this organ from any adhesions laterally. This mobilization on either side of the urethra will allow room for sutures to be placed to invaginate the urethra and carry it posteriorly to its normal position.

At this point a Foley No. 12 catheter is placed in the bladder and distended. The urethra is measured and its angle in relation to the bladder is noted.

The urethra and the base of the bladder are carefully examined for any possible tears and to estimate the amount of plication necessary to restore and reduce the cystocele and urethrocele to their original position. The relaxation of the urethral musculature should also be examined in its relation to the vesical neck of the bladder.

releasing the lower portion of the bladder and accentuating the cleavage plane at this point. Two Allis clamps are now placed on the vaginal wall, including its whole thickness; the lower one about ¾ inch above the external os and the upper one about ½ inch above the lower clamp. Using a pair of straight scissors, and with the Allis clamps on the stretch, a transverse incision is made between them. This should include the whole thickness of the anterior vaginal wall and will open the avascular space just below the bladder.

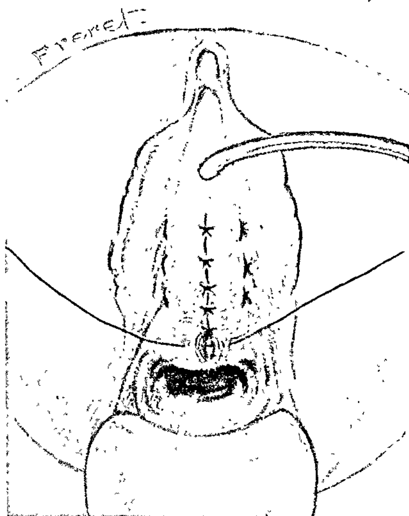


FIG. 9.—Mattress sutures tied, closing space between the plicated bladder and the anterior vaginal wall. The anterior vaginal wall is closed with interrupted sutures.

The initial scissors incision is enlarged laterally on either side slightly and the Allis clamps are removed and placed laterally on either side of the incision. If one has entered the proper cleavage plane, marked by a pocket formation of whitish color, the scissors, or preferably a Simms clamp, may be passed upward freely between the bladder and the anterior vaginal wall. The vaginal wall is now bisected through its entire thickness and the bladder is separated from

The first row of sutures should invaginate the attenuated and thinned-out portion of the bladder and should include the area at the vesical neck.

The second row of sutures should be placed to include the smooth and strong musculature of the bladder laterally and these should be tied without tension.

If at this point the urethra is not lengthened and not replaced posteriorly, a third row of sutures should be placed. The urethrocele and cystocele should now be well reduced with the urethra being in close contact with the Foley catheter.

The catheter may be left in place for bladder drainage so as not to put tension on the suture line.

Before trimming the vaginal flaps and closing the anterior vaginal wall, three mattress sutures are placed through the entire thickness of the vaginal wall. The first suture starts at the dimple on the left side of the vagina, is carried across to the opposite side and returned to its original point of entrance. One or two similar sutures are placed posterior to the first about ½ inch apart. These are not tied until the anterior vaginal wall is closed.

The vaginal flaps are now trimmed off and the anterior vaginal wall is closed with interrupted sutures. The three mattress sutures are tied after the closure. The vaginal wall is now brought snugly in contact with the bladder and urethra. The levator ani, bulbocavernosus, and deep transversus perinei are also brought in a better position to regain and maintain their function in controlling bladder continence.

CONCLUSIONS

An understanding of the anatomy and mechanism of the muscles of the urethra and voluntary perineal muscles is necessary in the treatment of stress incontinence.

The lines of cleavage must be followed in the approach to the bladder and urethra; this includes a thorough knowledge of the areolar connective tissue separating the anterior vaginal wall from the bladder, the fusion of the anterior vaginal wall to the urethra, the lateral line of cleavage of the perivaginal areolar tissue extending upward and lateral to the urethra and bladder under the symphysis.

Plication of the urethra and base of the bladder should start laterally and posteriorly to the urethra and include the vesical neck of the bladder, thus lengthening the urethra and reducing the urethrocele and cystocele.

A decided effort should be made to cure the primary case of urinary incontinence, however minor the incontinence may be.

The necessity of vaginal exercises is important to reactivate and regenerate the perineal muscles, both before and after operation. This reactivation of muscle tissue is often the margin of failure or cure of stress incontinence.

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Plication of the bladder, vesical sphincter and urethra is accomplished by the use of an intestinal atraumatic No. 00 chromic catgut suture. Mattress sutures are placed beginning laterally to the urethra and in the smooth tissue of the

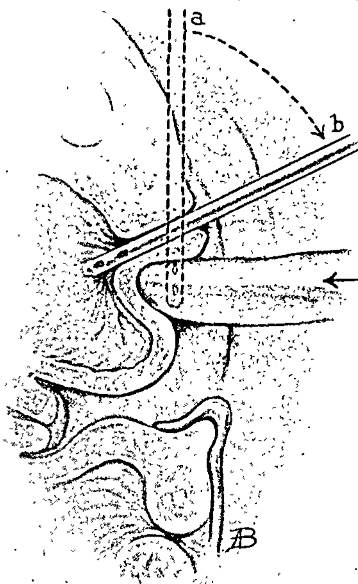


FIG. 11.—Manipulation of the catheter from within the vagina to produce a normal urethral angle. (Reich, W. J., Wilkey, J. L., and Silverman, H. E.: *Am. J. Surg.*, *70*.341, 1945.)

urethra under the symphysis. This is carried to the opposite side of the urethra and the suture is placed opposite its point of entrance. A series of mattress sutures is now placed in a similar manner, working posteriorly and invaginating the whole base of the bladder.

Transplantation of Fascia for Relief of Urinary Stress Incontinence

ALBERT H. ALDRIDGE, M.D.

It is unfortunate that we do not yet have complete knowledge of the anatomy of the urethra and its surrounding structures, or an entirely satisfactory understanding of the physiology of the delicate sphincter mechanism by which urination is controlled. For this reason it has been difficult to devise well defined surgical procedures which can be relied on to cure urinary stress incontinence. It is an accepted fact that not more than 80 to 90 per cent of women who have urinary incontinence due to loss of function of the urethral sphincter muscles can be cured by vaginal plastic surgery. Factors which contribute to unsatisfactory results or surgical failures are:

(1) Congenital underdevelopment of the urethra which in itself may cause incontinence or predispose to serious injury with a minimum of trauma.

(2) Loss of tissue substance due to the original injury, infection, and tissue necrosis.

(3) Increased tissue damage resulting from lack of judgment and skill in applying accepted vaginal plastic procedures for relief of incontinence.

(4) Irreparable damage to the blood vessels and nerves which supply the sphincter muscles.

Urethral function is not restored in some women who seem to have excellent vaginal plastic results following one or more operations by expert surgeons. However, as a rule, the urethra and the anterior vaginal wall will show relaxation and poor support which are responsible for the continued incontinence. The outlook for these women has often been most discouraging. They have had to adjust to the persistent leakage of urine and the conviction that the conditions from which they suffer may be incurable. Experience has proved that some of these women can be cured by a combination of vaginal plastic surgery and transplantation of abdominal fascia to support the urethra.

The author's interest in transplantation of fascia for relief of urinary stress incontinence was aroused in 1941 by efforts to cure a patient in whom constant leakage of urine for 29 years had not been relieved by three vaginal plastic operations. Following a fourth vaginal plastic combined with transplantation of fascia from the abdominal wall this patient has been completely continent and free of bladder symptoms for 10 years.

Transplantation of adjacent tissues to provide support for the urethra and to develop a substitute sphincter-like action for the one which had been lost was not a new idea at the time. From about 1900 numerous surgical technics had been described for transplantation of the fascia, the round ligaments, and the various

Frost, I. F.: An Evaluation of Certain Factors Pertinent to Surgery of the Anterior Vaginal Wall. *Urol. & Cutan. Rev.*, *51*:67, 1947.

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that a fascial transplant combined with a vaginal plastic may effect a cure of stress incontinence.

The procedure should be started with a plastic on the anterior vaginal wall and urethra to eliminate a cystocele, if present, and to accomplish as much as possible toward relieving the incontinence. For the urethra this will usually involve reduction of the caliber of its lumen to a size which is recognized as normal, repair of the damaged sphincter muscles, replacement of the urethra to a normal position beneath the pubic arch, and construction of a proper support from the surrounding tissues. The best known procedure for this purpose is the one devised by Kelly. However, we believe the operation developed by Kennedy, involving wider dissection and repair of the urethra, is more likely to succeed.

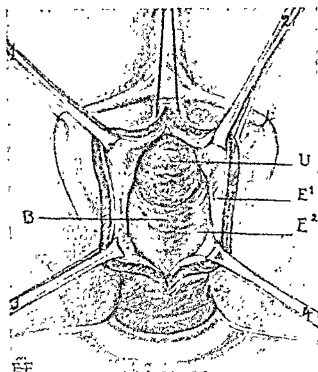


Fig. 2.—Anterior vaginal wall opened, exposing the muscular walls of the urethra and bladder. (U) urethra; (B) bladder; (E^1) connective tissue layer on the outer bladder surface of the vaginal wall; (E^2) connective tissue layer on the bladder wall.
(*Am. J. Obst. & Gynec.*, *44*:398, 1942.)

Figures 1 to 8 inclusive show steps in the procedure devised by the author, by which a sling of aponeurotic abdominal fascia is used to support the urethra, following a Kennedy type of vaginal plastic operation for stress incontinence.

Figure 1 is a schematic drawing of a sling developed from aponeurotic strips of fascia from the abdominal wall to support the urethra.

Figures 2 and 3 show dissection of the anterior vaginal wall and structures about the urethra. In Fig. 2, the midline incision has been carried through the entire thickness of the vaginal wall including the mucosa, the smooth muscle, and a thin dense layer of fascia (E^1) on its bladder surface. The incision ex-

muscles including the pyramidalis, rectus abdominis, gracilis, levator ani, and bulbocavernosus. The names connected with these procedures—Goebell, Frangenheim, Stoeckel, Giordano, Squier, Thompson, Miller, Martius, and Price—and their contributions are well known. Invariably their special technics had been developed for women who had not been relieved of incontinence by vaginal plastic surgery. A review of the details of these technics shows that when fascial straps were used they were brought to the urethra close to the upper or lower surfaces of the pubic bone. *By doing so the fascial slings originated from fixed* points in the abdominal wall, preventing any mobility of the sling to provide uniform support for the urethra during rest and physical strain, that is, with changes in intra-abdominal pressure and relaxation and contraction of muscles

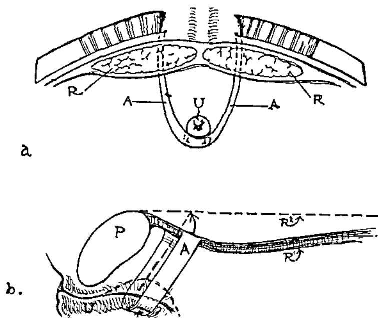


Fig. 1.—(a) Diagrammatic representation of a technic for transplanting strips of aponeurotic fascia for cure of urinary incontinence: (A) Strips of aponeurotic fascia; (U) urethra; (R) recti muscles. (b): (U) urethra, (P) pubic bone; (A) fascial sling; (R¹) relaxed position of the recti muscles; (R²) position of the recti muscles when contracted as with straining. (*Am. J. Obst. & Gynec.*, *44*:398, 1942.)

in the abdominal wall. *Furthermore, it would seem impossible to transplant* the various muscles or fragments of muscles to positions recommended without almost complete destruction of their nerve and blood supply. As a result, the transplanted muscles could hardly be expected to retain any contractility which might produce a substitute sphincter-like action for the urethra.

In a high percentage of women in whom vaginal plastic surgery has failed to cure stress incontinence it will be obvious that the result might be improved by another vaginal plastic. However, experienced surgeons are aware of the technical difficulties of such procedures and the decreased chances of success on account of scar tissue resulting from previous operations. They hesitate to subject a patient to another operation which may fail. It is in such circumstances

tends forward to within 1.5 cm. of the external urinary meatus. The thin layer of fascia (E^1) on the bladder surface of the anterior vaginal wall and a similar layer (E^2) on the lateral surfaces of the bladder are believed to be surface condensations of fascia which support muscle fibers in the walls of the vagina and bladder. Between E^1 and E^2, there is a thin, almost bloodless layer of loose areolar fascia, a part of the endopelvic fascial system. It is in this layer that extensive, almost bloodless dissection can be carried out.

Figure 3 shows fascial layers (E^1 and E^2) being held under tension by Allis clamps (2, 4, 5, and 6).

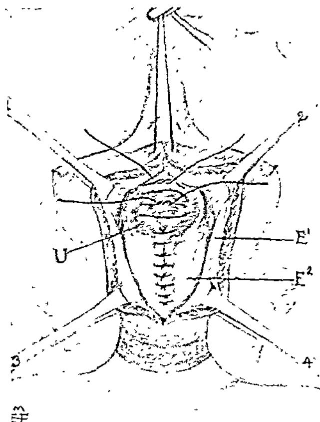


FIG. 5.—The wall of the urethra (U) is folded in with mattress sutures to reduce its caliber and to reunite the torn ends of the sphincter muscles. The mesial margins of the connective tissue layer (E^2) on the bladder have been brought into apposition with chromic catgut sutures. (*Am. J. Obst. & Gynec.*, *44*:398, 1942.)

Figure 4 shows how, by blunt dissection, the index finger can be passed between layers E^1 and E^2 upward and forward between the pubic arch and lateral surfaces of the bladder and urethra nearly to the anterior abdominal wall. This is in part the type of dissection recommended by Kennedy for his operation for stress incontinence. Incidentally it opens spaces through which fascial straps can be safely brought down from the abdominal wall to form a sling to support the urethra.

Figure 5 shows placement of sutures used in the vaginal plastic part of the procedure. With interrupted sutures of fine chromic catgut the relaxed muscular

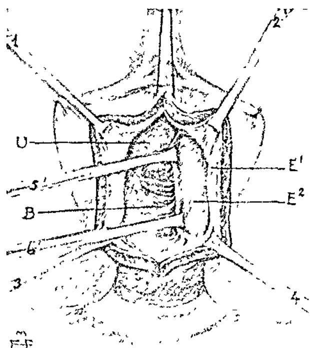


Fig. 3.—Connective tissue layers (E^1) on the vaginal wall and (E^2) on the bladder wall being held under tension by the use of Allis clamps (2, 4, 5, and 6).
(*Am. J. Obst. & Gynec.*, 44:398, 1942.)

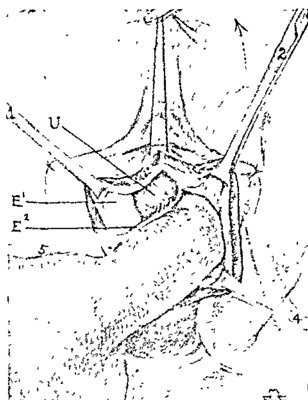


Fig. 4.—The plane of cleavage between (E^1) and (E^2) shown in Fig. 3 has been opened laterally and forward by blunt dissection. The finger is being passed through this opening forward and above the pubic bone at the left of the urethra (U).
(*Am. J. Obst. & Gynec.*, 44:398, 1942.)

turbance to their nerve and blood supply; (2) the fascial sling originates and is fixed at a point in the abdominal wall, well above the pubic crest. This permits the sling to move and to maintain uniform support for the urethra during changes in position of the abdominal wall associated with rest and physical strain.

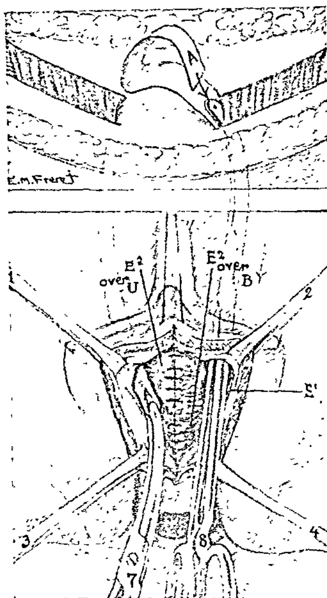


Fig. 7.—Clamps (7 and 8) passed forward in the spaces opened by finger dissection, as shown in Fig. 4, are being used to grasp the fascial strips (A) and to draw them into the vaginal wound with one on either side of the urethra.
(*Am. J. Obst. & Gynec.*, *44*:398, 1942.)

In 1948 Millin and Read of London reported on Millin's fascial sling technic for relief of urinary stress incontinence. Fascial straps for the sling were developed through a Pfannenstiel incision by a simple method which retained their normal attachments to the muscles of the abdominal wall. The sling was formed by passage of the free ends of the fascial straps through a space between the

wall of the urethra is folded in, to reduce the caliber of its overstretched lumen and an effort is made to repair the relaxed and injured urethral sphincter muscles. The margins of the fascial layers (Fig. 2, E^2) on the lateral surfaces of the bladder are then brought into apposition in the midline with superficial interrupted sutures of fine chromic catgut. This line of sutures is carried as far forward as possible over the urethra. By doing so the bladder is given support to cure the cystocele, and the urethra is displaced backward to a normal position. Structures about the inner end of the urethra can also be reinforced with mattress sutures of silk or linen placed in the fascial layers (E^2).

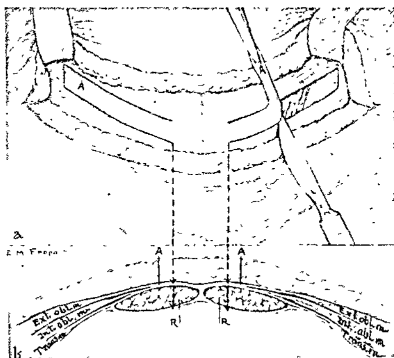


FIG. 6.—(a) Fascial strips (A) from the aponeurosis of the oblique muscles are being separated through a Pfannenstiel incision. (b) The dotted lines indicate points about 2 cm. from the mesial margins of the recti muscles (R) through which the fascial strips (A) are passed backward before encircling the urethra.
(*Am. J Obst. & Gynec., 44*:398, 1942.)

After completing the vaginal plastic operation, fascial strips, prepared as shown in Fig. 6, through a Pfannenstiel incision, are brought down into the vaginal wound by clamps (7 and 8), as shown in Fig. 7. The fascial straps should be about 1.5 cm. in width and should be developed about 4 cm. above the upper border of the pubic crest. The importance of this point in technic is that it permits the completed sling to move with changes in intra-abdominal pressure and in position of the abdominal wall, thereby maintaining constant support for the urethra.

The author believes the advantages of the sling technic which he devised are that: (1) the rectus abdominis muscles are always well developed and in a position where they can be readily used for urethral support without dis-

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proximal end of the urethra and the vaginal wall. This was accomplished by dissection through the abdominal wound. To facilitate the dissection a Malecot or Foley catheter was placed in the bladder and a special clamp was used for the final steps in the dissection and to assist in placement of the fascial straps beneath the urethra. The procedure was used for 140 women with only one known failure. Millin and Read's decision to use a fascial sling alone for treatment of urinary stress incontinence was based on the conviction that this condition is caused chiefly by loss of support of the proximal end of the urethra and vesical neck. Their results are remarkable if the assumption is correct that many women in their series, treated by sling alone, had had vaginal birth injuries which were not repaired.

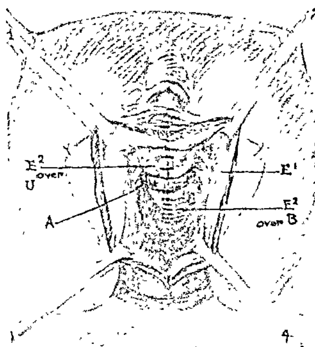


Fig. 8.—The fascial strips (A) have been united in the midline to form a fascial sling beneath the urethra at its junction with the bladder.
(*Am. J Obst. & Gynec.*, *44*:398, 1942.)

In the treatment of urinary stress incontinence approximately 4 out of 5 women can be cured by vaginal plastic operations. The fascial sling procedure is a method by which some women can be cured when vaginal plastic surgery has failed. It may prove to be useful for nulliparous women in whom incontinence is due to congenital underdevelopment of the urethra. The procedure should probably be reserved for women in whom vaginal plastic surgery has failed and should be combined with a vaginal plastic in women who have obvious birth injuries which might cause incontinence.



Fig. 1.—A nylon bag is tied between the thighs.

Frontal Position. The patient must bend somewhat forward for the reduction of the semiaxial projection of the urethra, and the exposures are made as follows.

	Target-film distance	*KV*	*MAS*
Thin patient	90	90	120
Obese patient	90	100	240

Lateral Position. A metal ruler is placed in vertical position on the mons pubis in order to allow direct measurements on the pictures, and the exposures are made as follows:

	Target-film distance	*KV*	*MAS*
Thin patient	90	120	260
Obese patient	90	120	320

A normal cysto-urethrogram made with this technic is shown in Fig. 2, and one of stress incontinence in Fig. 3. Figure 4 shows the same patient after a pubococcygeal repair was made and the bladder replaced to its normal position behind the symphysis.

The frontal position gives information as to the shape of the bladder and the funneling of the bladder neck. In typical cases of stress incontinence the bladder is like a bellflower, when the patient is straining or during micturition. We have, however, found the lateral position most valuable as it makes exact

The Use of the Pubococcygeal Muscles in the Repair of Stress Incontinence

AXEL INGELMAN-SUNDBERG, M.D.

The objective of my method (Ingelman-Sundberg, 1946, 1947, 1950) is to restore the physiologic condition by adding a muscular support to the connective tissue sutured under the bladder neck. The pubococcygeal muscles are used. They are cut slightly posterior to their midpoint; thus preserving their contractive power. There will be no tension owing to the division of the muscles, and as the contractility is preserved and increased by suitable exercises, the plastic repair should be very durable. The operation also creates a type of suspension, which, in the event of a future delivery, will be located to the side of the birth canal proper, and not exposed to a direct separation by the fetal head. My personal experience includes 103 cases, 31 of which have been observed from four to six years. There have been no deaths and no recurrences in spite of the fact that 2 patients were later delivered.

INDICATIONS FOR SURGERY

Patients suffering from urinary incontinence due to neurogenic disturbances will not be cured by this operation and must be excluded. The anamnesis must therefore be carefully studied, and the cystometry curve must be normal, without spikes indicating an uninhibited bladder. The sensitivity of the bladder should be tested by using hot and cold water, and with the tip of the cystoscope or an ureteral catheter. The movements and the shape of the internal sphincter should, if possible, also be studied during urethrocystoscopy. The sensitivity of the urethra and the perineal region, and the contractility of the pubococcygeal, perineal, and anal muscles must be investigated. All of these findings are normal in typical cases of stress incontinence. A typical roentgenogram made during micturition is also necessary. Dr. Nordenström of the Roentgen Department of Sabbatsbergs Hospital has worked out the following technic for this examination, which I have found very useful.

Technic of Cysto-urethrography (B. Nordenström)

Barium meal in water suspension in the proportion 1:2 by weight is used. Sterilization is done by boiling, and the lukewarm solution is injected slowly through a catheter until the patient feels the desire to urinate. The catheter is then removed, and a nylon bag is tied between the thighs (Fig. 1). The patient is examined standing, in frontal and lateral positions with the legs apart, and exposures are made in the attitudes of "rest," "voiding," and "holding."

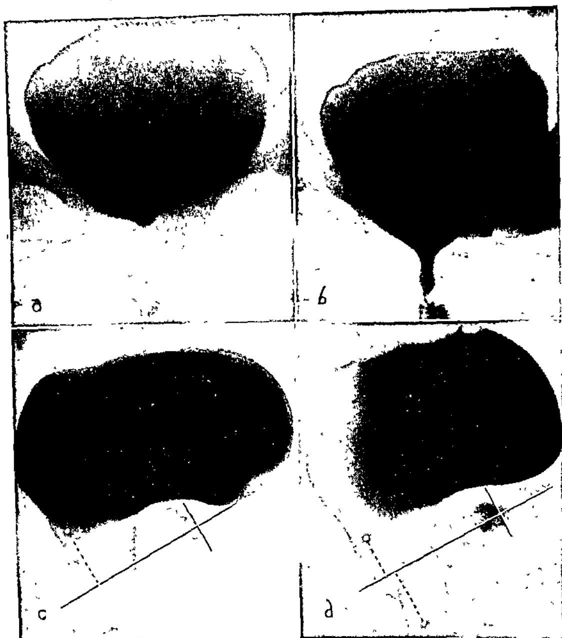


Fig. 3.—Preoperative cystograms in a case of stress incontinence: (a) the bladder at rest, frontal view; (b) during micturition, frontal view; (c) at rest, lateral view; (d) during micturition, lateral view.

OPERATIVE TECHNIC

Local anesthesia is used, and may be combined with intravenous anesthesia, nitrous oxide and oxygen, or trichlorethylene. A thorough infiltration makes the dissection easier, especially if there is much scar tissue.

The operative technic varies with the anatomic conditions, and special variations are found on page 117. In most cases the following procedure is the best:

(1) A transverse incision is made under the external urethral meatus (Fig. 5).

(2) The anterior vaginal wall is dissected from the urethra and from the blad-

measurements possible concerning the ptosis of the bladder neck and its distance from the symphysis. For that reason a line is drawn on the lateral films through the center of the symphysis and through its upper border. This latter point is used as the origin of a co-ordinated system, as shown in Figs. 3 and 4, making it possible to give an exact definition of every detail of the bladder and the urethra.

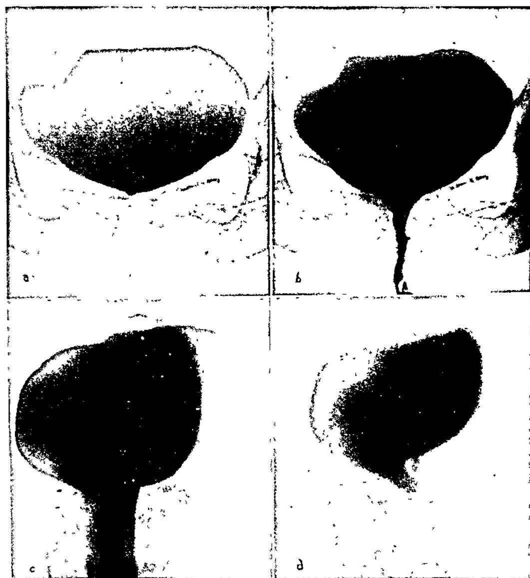


FIG. 2.—Normal bladder control: (a) at rest, frontal view; (b) during micturition, frontal view; (c) at rest, lateral view; (d) during micturition, lateral view.

PREOPERATIVE CARE

Any urinary infection must be cured. Estrogenic hormone is given for some days if the vaginal mucous membrane is atrophic. The patient is taught to perform pubococcygeal exercises.

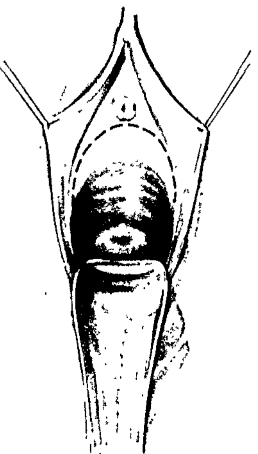


Fig. 5

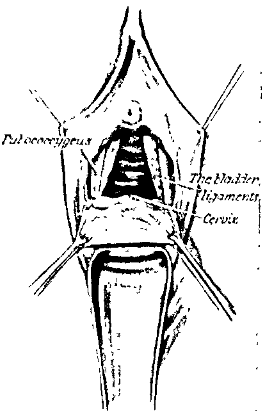


Fig. 6

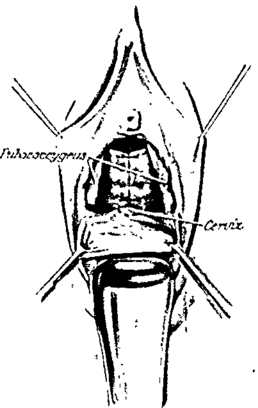


Fig. 7

der by a knife and small sponges up to the cervix (Fig. 6). When the cervix l been reached, the external os is grasped with a tenaculum. The bladder is th pushed up on the cervix in the usual way.

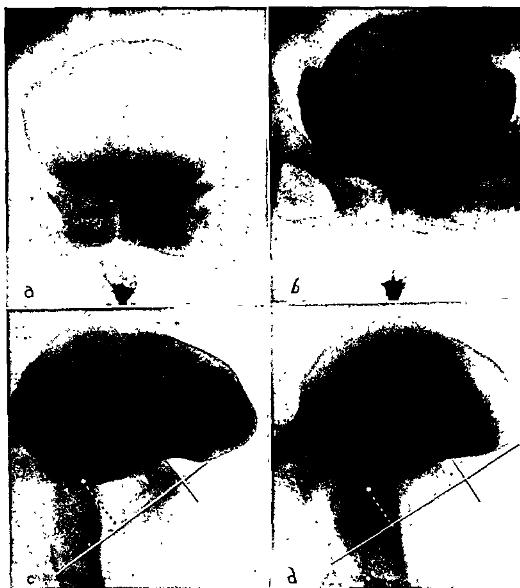


FIG. 4.—Same case as shown in Fig. 3, after operation: (a) the bladder at rest, frontal viev (b) during micturition, frontal view, (c) at rest, lateral view; (d) during micturition, later position.

(3) The bladder ligaments (pelvic fascia) are laid free as far as possibl on the sides. They are sutured with chromic catgut in the midline under th neck and the floor of the bladder as a fascial plate, in order to return th bladder neck to its normal position behind the symphysis, and to cover a eventual cystocele. The posterior part of the plate is sutured to the cervix (se Fig. 7).

(4) By blunt dissection laterally the pubococcygeus muscles are freely exposed as far as symphysis and are cut slightly behind the midpoint. Two anterior portions attached to the symphysis are produced thereby, and two posterior parts fastened to the coccyx. During this procedure one must be careful not to cut the pudendal nerve. A suture with long ends is placed in each of the posterior muscle portions in order to facilitate the location in step 5 (Fig. 8). The anterior muscle portions are fixed together by interrupted sutures of heavy chromic catgut or thin stainless steel wire to a muscular support under the bladder neck

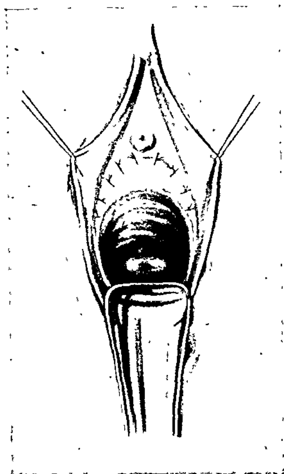


Fig. 11

beneath the fascial layer (Fig. 9). When the muscles are well developed, a muscular plate is made covering the whole bladder floor, and the posterior part of this plate is fixed to the cervix in the same way as the underlying fascial plate.

(5) The posterior pubococcygeus portions are sutured laterally, each to the corresponding ischiocavernosus muscle in cases where no proctocele is present, and where the perineum is normal (Fig. 10). The anterior vaginal wall is then fixed to the muscular plate with a few sutures of fine catgut, and the incision is closed, as shown in Fig. 11. A Foley catheter is placed in the bladder, and the vagina is sponged well with gauze powdered with microcrystalline sulfathiazole and penicillin.

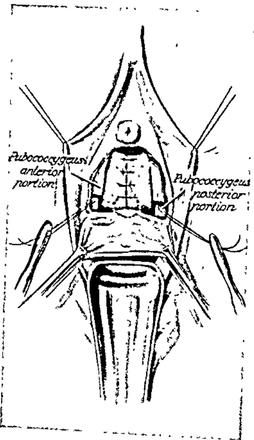


Fig. 8

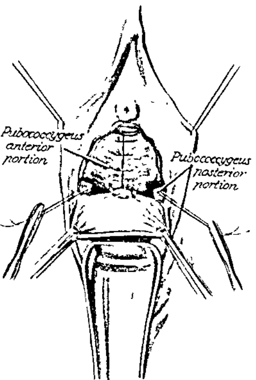


Fig. 9

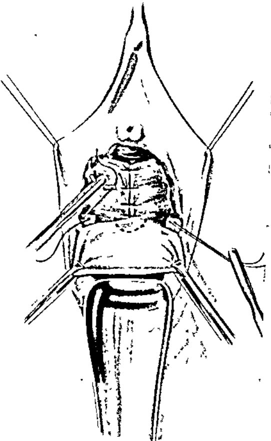


Fig. 10

VARIATIONS OF THE TECHNIC

(1) In cases with a descensus of the uterus an amputation of the cervix or a hysterectomy is first done, according to current methods. The operation is then performed as described.

(2) If a proctocele is present, or if a perineal repair is indicated, *step 5* is carried out as follows: The posterior portions of the pubococcygeal muscles are located through a longitudinal incision in the posterior wall of the vagina in such a way that after sufficient mobilization of the lateral vaginal walls the

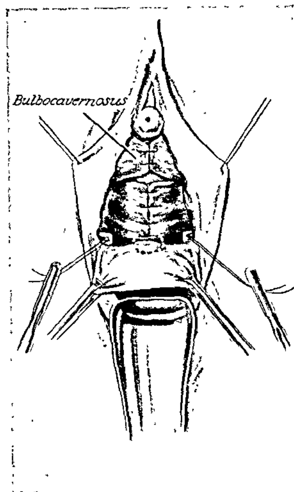


FIG. 15

sutures applied in the posterior muscle portions in step 4 are grasped with a clamp, and the muscles brought into the incision (Fig. 12). The muscles are then fixed by interrupted sutures of chromic catgut. At the same time an enterocele or a proctocele is repaired. Perineal repair is done if the perineum is in poor condition, and the anal sphincter is sutured if it is ruptured. Redundant tissue is cut away and the mucosa is sutured with fine catgut, as shown in Fig. 13.

(3) The following technic is used in cases where a large urethrocele is present: Step 1: A triangular flap of the mucosa is dissected in such a way that the

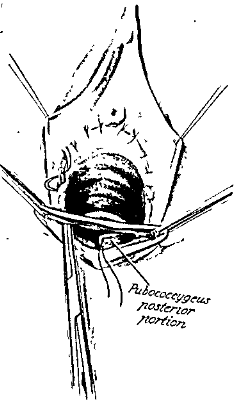


Fig. 12

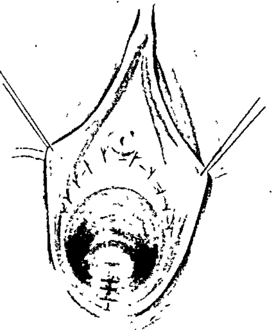


Fig. 13

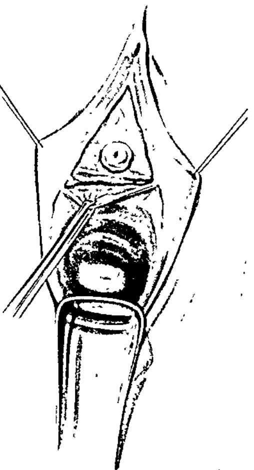


Fig. 14

uterus, if the patient is not fertile, or else a sling operation. After the peritoneum has been closed, the bladder ligaments are sutured as described in Step 3. The corpus is then fastened to the periosteum of the pubic arch and to the pubococcygeal muscles, which are sutured to the uterus with thin stainless steel wire.

POSTOPERATIVE CARE

The tampon is removed after 24 hours and so is the catheter, when the patient can empty her bladder, generally within seven to 10 days after the operation. The patient is allowed to sit up in a chair and walk around for about an hour every day. She can usually be discharged on the 16th day. She is then instructed to take exercises in contracting the pubococcygeal muscles in order to strengthen the pelvic floor.

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apex is near the clitoris, and the base just above the vaginal inlet. A sleeve of the mucous membrane is left around the opening of the urethra. Then the incision is extended to the middle of the vaginal side wall (Fig. 14).

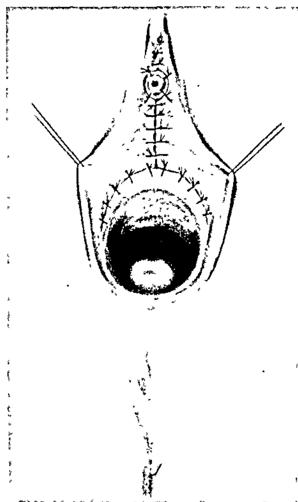


Fig. 16

Steps 2-4 are done as described. After this the bulbocavernosus muscle is laid free on both sides and sutured in the midline as a support for the distal part of the urethra (Fig. 15). The muscle is fixed by a few interrupted sutures of chromic catgut, and the connective tissue on both sides of the muscle is sutured in separate layers with very fine catgut. It is important that the introitus does not become constricted. The orifice of the urethra is then sutured in the anterior part of the wound near the clitoris, and the vaginal wall is fastened with a few sutures of fine catgut against the underlying tissue, and sutured as shown in Fig. 16.

Step 5 is then carried out as described earlier.

(4) If the bladder ligaments and the pubococcygeus muscles are found to be poorly developed at Step 2, it is better to make a vesicovaginal interposition of the

had suffered from incontinence for 10 years or more, symptoms begin to improve after a few weeks or even after only a few days of muscle education and resistive exercise with the aid of the Perineometer. Such a brief period of physiologic therapy is obviously much too short to bring about anatomic changes in the muscle and consequent correction of bladder position or periurethral tension.

The fact that it is possible to influence urinary stress incontinence through muscle education alone, before little if any anatomic change can have taken place, points to a borderline deviation from the normal mechanism of micturition. It seems most likely that insufficient function of the neuromuscular reflex has been corrected through a measure operative precisely at the urinary outlet where the bladder—the holding organ—connects with the urethra—the emptying organ. Thus a reflex component in urinary stress incontinence and normal micturition is demonstrated which is confined to a small control area. Based on this finding it is possible to reconcile the etiologic concept of physiologic therapy with that of the various successful surgical procedures (Muellner). At the present time it is not possible to distinguish with any degree of certainty between functional and structural components of urinary stress incontinence. Until further evidence has been accumulated it must therefore be assumed that urinary stress incontinence may be caused by structural defects or muscular dysfunction, but in the majority of instances the condition is probably due to a combination of both factors.

Specifically, injuries due to childbirth or surgical interventions are often only precipitating factors in a pre-existing borderline dysfunction. Many of these patients give a history of so-called bladder weakness since childhood, and urinary stress incontinence is also encountered in nulliparous women, following cesarean section, and after the best of obstetric care. Furthermore, the prompt response of many patients with urinary stress incontinence, apparently due to degenerative processes occurring in the course of protracted illness, the menopause, or senile involution, suggests a functional disturbance which predisposed to the development of the urinary complaint.

ANATOMIC BASIS OF PHYSIOLOGIC THERAPY

The neuromuscular reflex in the region of the bladder neck responds to therapeutic restoration of function of the pubococcygeus muscle. As Anson has recently demonstrated, innumerable minute interdigitating end-fibers of the pubococcygeus are inserted into the intrinsic musculature of the proximal urethra and the middle third of the vagina. Apparently these end-fibers constitute the link between the main body of the muscle, which normally is under voluntary control, and the urinary reflex.

The pubococcygeus muscle as a whole is accessible through the vagina. Quality of structure and degree of function can be ascertained through palpation, and strength of contractions measured with the aid of the Perineometer. The principles of therapeutic muscle education and resistive exercise, as employed in the restoration of function of other skeletal muscles, can be applied to the pubococcygeus by the vaginal route (Read).

Physiologic Therapy of Urinary Stress Incontinence

ARNOLD H. KEGEL, M.D.

PHYSIOLOGIC THERAPY consisting of muscle education and resistive exercise of the perivaginal muscles was first employed by the author in 1932 to improve the unsatisfactory results of plastic surgery of the perineal structures (Kegel, 1948). On the basis of this experience the usefulness of the new method in conjunction with other plastic operations of the pelvic outlet was explored (Kegel, 1951). In March, 1947, physiologic therapy was applied in a case in which a plication type of operation, performed six months previously, had failed to relieve urinary stress incontinence. After two weeks of muscle education and resistive exercise with the aid of a Perineometer the patient became entirely free of symptoms and has remained continent to date (Kegel and Powell). Since then, physiologic therapy for the relief of urinary stress incontinence has been successfully employed following failure of other types of corrective operations by the vaginal or abdominal route, and also routinely as primary treatment of urinary stress incontinence. Its special field of application includes debilitated patients and the large group of women who suffer from incontinence to an annoying or embarrassing degree, yet too slight to warrant surgical intervention (Counseller). In the latter group, physiologic therapy has proved almost 100 per cent successful.

ETIOLOGY

The physiologic approach to the problem of urinary stress incontinence is based on findings of physical examination (Kegel, 1949) and on a therapeutic test It has been observed that urinary stress incontinence is always associated with clinical evidence of poor function of the pubococcygeus muscle. Furthermore, it has been the experience in more than 1,000 cases of urinary stress incontinence treated by muscle education and resistive exercise that *lasting* symptomatic relief will occur only after improved function of the pubococcygeus muscle can be demonstrated clinically.

Function of the pubococcygeus is therefore an important factor in urinary control. This finding can be correlated with the good results obtained by various types of vaginal and abdominal operations for the correction of urinary stress incontinence, since all of these procedures may directly or indirectly affect the physiologic tension of the pubococcygeus muscle and its visceral extensions.

While increase in muscular tension and change of anatomic position of bladder and urethra have thus contributed to restoration of urinary control, still another factor becomes evident on the basis of results obtained through physiologic therapy. It has been our experience that in 75 per cent of women, some of whom

peated efforts will finally enable her to transfer these muscular actions of which she is cognizant to a higher level.

It is emphasized that awareness of function of the pubococcygeus muscle must be *firmly* established before clinical results can be expected. Approximately 75 per cent of patients will respond after 10 to 20 minutes of instruction. All patients, however, must be carefully checked at weekly intervals lest they revert to the faulty old habit of using muscles other than the pubococcygeus. In approximately

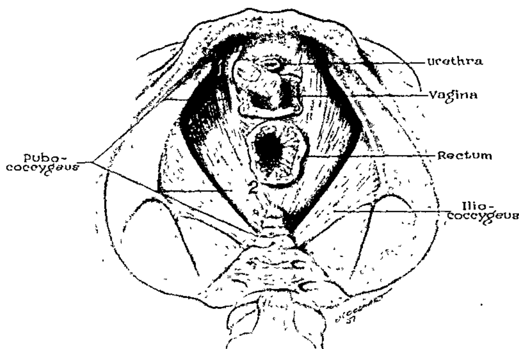


FIG. 1.–Identification of contractions of the pubococcygeus muscle. (1) The tip of the index finger is in contact with the medial margin of the pubococcygeus at the level of the urethra (abdominal view). (2) In limited awareness of function of the pubococcygeus, slight (secondary) contractions can usually be felt posteriorly, where the fibers of the muscle converge for attachment to the coccyx.

25 per cent of cases considerably more time and persistence are necessary before patients learn to contract the pubococcygeus. Awareness of function has eventually been established in all cases not complicated by lesions of the central nervous system–some patients responding only after six to 12 months of concentrated effort.

At home, daily repetition of correct contractions, as taught by the physician, is facilitated by use of the Perineometer. This apparatus provides a means of visual control of muscular efforts, and enables the patient to observe any slight progress.

TECHNIC OF PHYSIOLOGIC THERAPY

Diagnosis

With the index finger introduced to a depth of 3 to 5 cm., tone and function of the pubococcygeus are determined by palpation in the middle third of the vagina. Normally, the vaginal canal at this point is tight and the firm walls shape themselves snugly around the examining finger. Contractions can be felt in the entire circumference (Kegel, 1951).

Atrophy of the pubococcygeus and its visceral extensions is characterized by marked roominess of the middle third of the vagina, beginning immediately within the introitus. The canal is shortened, the walls feel thin, and give the impression of being detached from the surrounding structures. The findings are *most significant in the anterior and lateral aspects of the middle third of the vagina.*

Function of the pubococcygeus *is ascertained through the patient's response to* efforts at contraction. Normally strong contractions are palpable in the middle third of the vagina, and when measured with the Perineometer show contractile strength *equivalent to 20 mm. Hg,* or more *(above initial static pressure). In* patients with urinary stress incontinence contractions are weak or absent, and when measured with the Perineometer rarely result in readings of more than 5 mm. Hg (above initial static pressure). Awareness of function is lacking, and many patients state that they did not know that it is possible to contract the perivaginal muscles.

Muscle Education

The aim of muscle education is to establish full awareness of function of the pubococcygeus. To this end it is necessary for the physician to discover any muscular activity in the perineum which may result in even slight contractions of the pubococcygeus. Once such contractions are elicited they are identified for the patient.

Faint contractions of the pubococcygeus are most readily discovered in two places: (1) near its attachment to the os pubis; (2) posteriorly, where the fibers converge for attachment to the coccyx (Fig. 1).

If no tensing of the pubococcygeus can be felt as the patient exerts voluntary effort to contract the muscles in the middle third of the vagina, various maneuvers are available to induce such contractions. The patient is requested to draw *up or draw in the perineum as a whole; contract and draw up the rectum* as though checking a bowel movement; contract as though interrupting the flow of urine while voiding. (Mere puckering of the anus or twitching of the urethral meatus without *retraction* is of no value.)

Should these maneuvers fail to induce contractions of the pubococcygeus itself, antagonistic action of the muscle may be elicited by exerting digital pressure to the point of discomfort against the posterior plate of the levator ani (Fig. 2). In obstinate cases reflex contractions may be produced by pricking the skin lateral to the rectum.

Through these various procedures concomitant synergistic contractions of the pubococcygeus are produced and brought to the attention of the patient. Re-

patient (Kegel, 1948). Only a slow and gradual increase of readings is physiologic, and any sudden changes indicate use of extraneous muscles, such as those of the abdominal wall, thoracic diaphragm, external sphincters, or gluteal and thigh muscles. Complaints of fatigue, irritability, or discomfort are generally due to use of extraneous muscles and exertion of unnecessary effort. In the few instances in which sexual excitation was noted, it occurred on a psychologic basis.

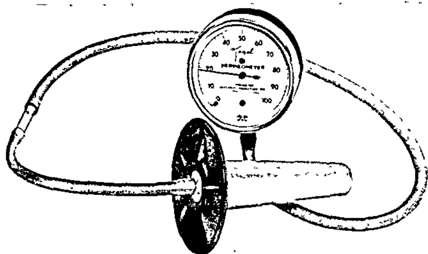


FIG. 8.—The Perineometer employed in muscle education and resistive exercises of the pubococcygeus muscle. Strength and function of the perivaginal muscles are developed through contractions against progressive resistance offered by the pneumatic cylindric diaphragm. The manometer serves as a visual guide in establishing awareness of contraction of the pubococcygeus muscle.

Muscle education and resistive exercise correctly and diligently performed establish an action pattern which will rarely be lost again. Strong, sustained contractions produced by voluntary effort can be palpated where none could be felt before, particularly in the anterior vaginal wall. Continued exercises will result in improved tone and texture of all supportive and sphincteric tissues (Jones), and in changes in the position of the urethra, the bladder neck, and the other pelvic viscera.

ACTIVE EXERCISE WITHOUT THE PERINEOMETER

Once contractions of the pubococcygeus and its visceral extensions have been firmly established as a reflex pattern, the patient is able to continue exercises without the aid of the instrument. Women differ greatly in the degree of their lack of awareness of function, and also in the time required for muscle training.

Active exercises attempted without the instrument, even after adequate instruction, have proved of questionable value. In some cases good immediate results were obtained, but recurrences were frequently noted; in other patients response was poor or entirely lacking. Thus a period of exercise with the instrument is suggested in order to start the patient correctly, to avoid time-consuming reinstruction, and to spare her disappointment and discouragement.

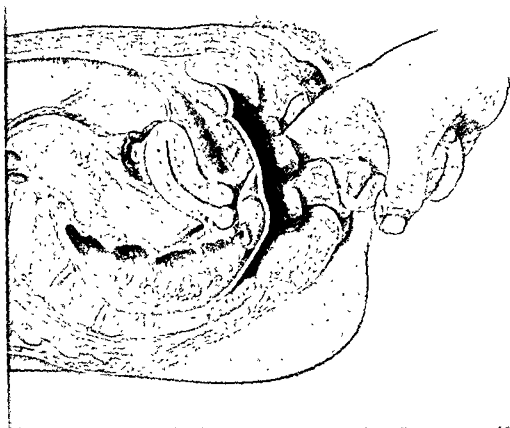


FIG. 2.—Method of inducing the patient to contract the posterior plate of the levator ani. Pressure with the index finger against the posterior plate usually produces an antagonistic contraction. Adequate repetition will aid the patient in learning to contract the pubococcygeus muscle.

RESISTIVE EXERCISE

Full strength and function of the pubococcygeus and its visceral extensions are developed by contractions against increasing resistance, as made possible by the pneumatic chamber of the Perineometer (Fig. 3). The cylindrical shape of the resistance chamber permits exercise of muscles in the entire circumference of the vagina, and judging from the therapeutic results the effect extends to the end-fibers of the pubococcygeus inserted into the musculature of urethra and/or bladder neck.

After it has been made certain that the patient is using the Perineometer correctly, she is instructed to exercise with the aid of the instrument at home, 20 minutes three times daily, or for a total of at least 300 contractions a day. In addition, she is advised to perform frequent contractions of the pubococcygeus without the instrument.

A weekly check on the correctness of resistive exercises is necessary for one month or longer, and is facilitated by means of a progress chart kept by the

Partial relief or failure occurred in 16 per cent of patients and could be traced to local or general *complicating factors.* These included marked shortening and scarring of the anterior vaginal wall resulting from previous surgical procedures of radium therapy, neurologic changes, mental deficiency, senility, advanced diabetes, and obesity.

In general, success of physiologic therapy in the presence of complicating factors depends largely on the degree of neurologic involvement. The results obtained in multiple sclerosis were practically all negative, those in poliomyelitis were slightly more favorable. Residual incontinence following minor spinal cord injuries was relieved in 2 patients. Results in diabetic patients who responded well to general therapy were satisfactory. In 16 markedly obese patients good results were obtained when physiologic therapy was combined with a regimen for weight reduction. For senile and mentally deficient patients an extended trial period is suggested, provided they are able to comprehend and follow instructions.

Scarring and loss of elasticity of the tissues are often observed after multiple operations in the region of anterior vaginal wall and bladder neck, including vaginal hysterectomy and interposition procedures. Resistive exercises diligently applied over a sufficient period of time resulted in softening, increased tone and resilience of the structures, and subsequent relief of urinary stress incontinence. In 3 instances there remained constricting fibrous bands extending from the vault of the vagina to the region of the bladder neck, and relief of urinary stress incontinence was not obtained until the bands were released through minor plastic surgery.

PHYSIOLOGIC THERAPY IN RELATION TO SURGERY

Valuable observations were made in the series of 66 cases in which physiologic therapy was applied following surgical failure.

(1) Simple plication of periurethral tissues (Kelly stitch) did not interfere with subsequent physiologic therapy.

(2) Following surgical procedures involving extensive dissection of structures attached to the urethra and bladder neck, response to physiologic therapy was slow and the results were in some cases incomplete. Postoperative hemorrhages and hematomas were reported in several cases.

(3) Good results were obtained with physiologic therapy in those cases in which urinary control was satisfactory in the immediate postoperative period, and recurrence was due to further genital muscle relaxation, months or years later.

(4) When urinary control was not restored immediately following surgical intervention, or incontinence was made worse as in some cases, the results of physiologic therapy varied. It is assumed that in those cases in which good results were obtained through muscle education and resistive exercise the operation had failed to reach the control area. Poor results from physiologic therapy in this group are thought to be due to severance or faulty healing of essential muscular attachments.

(5) Following plastic procedures involving the anterior vaginal wall physiologic therapy encountered greater difficulties when the anterior vagina had

Special Measures

Patients suffering from urinary stress incontinence usually have formed the habit of restricting fluid intake. In order to increase the use of the muscles of the bladder outlet they are advised to drink 10 or more glasses of water a day, and to stop the flow of urine several times while voiding. The contractions which resulted in interrupting the stream should be remembered and immediately duplicated in exercises with the Perineometer. The use of vaginal tampons which exert pressure on the bladder neck to control the urine is discontinued since they interfere with the urinary reflex and contribute to atrophy of the pubococcygeus. For the same reasons perineal pads to absorb the urine are reduced in size and eliminated as quickly as possible.

INDICATIONS AND RESULTS

Physiologic therapy is indicated in all phases of true urinary stress incontinence (1) in simple or intermittent urinary stress incontinence, (2) in severe and complicated urinary stress incontinence, (3) as an adjunct to surgical correction, and following surgical failure, and (4) in prevention of urinary stress incontinence (Kegel, 1951).

Simple Urinary Stress Incontinence

Approximately 75 per cent of women treated for urinary stress incontinence complained of temporary loss of urinary control with coughing, sneezing, laughing, lifting, or other sudden strains. The condition was aggravated by illness, fatigue, nervous tension, etc., and usually became more marked following childbirth, during the menopause, and in senility.

In this group response to physiologic therapy is prompt, and symptoms usually begin to improve within two weeks of resistive exercise with the aid of the Perineometer. Urinary control under normal circumstances has been restored consistently in more than 400 patients in this group. Thus physiologic therapy provides a successful treatment for an annoying and embarrassing condition with undesirable psychologic side effects, which formerly was endured for many years until it became severe enough to warrant surgical intervention.

Severe and Complicated Urinary Stress Incontinence

Approximately 25 per cent of women in our series complained of almost constant dribbling and the reflexes of urination had been markedly weakened or practically lost. Usually pads were depended on to absorb the urine.

In this group of women awareness of function of the pubococcygeus is achieved with difficulty and progress is slow. It is often necessary to repeat instructions at weekly intervals for many months. Good urinary control, however, was established in 84 per cent of instances. Patients were able to discard their pads, and occasional recurrences following debilitating illnesses were controlled by resumption of resistive exercises for a few weeks. One hundred and forty-six patients had previously undergone one or more surgical interventions involving the anterior vaginal wall, and 60 major pelvic operations.

of antepartum and postpartum exercises, are highly promising (Bushnell; Miller and Hyde).

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been shortened and narrowed, thus creating tension instead of support in the region of the bladder neck. Apparently this is due to plication of the lateral structures at too low a level.

(6) In the presence of urethrocele and large cystocele, it has proved advisable to relieve urinary stress incontinence first, and to postpone repair of structural defects, when indicated. Thus sphincteric function of the bladder outlet is assured and the chances of affecting the incontinence adversely are reduced to a minimum.

(7) Successful application of physiologic therapy in the treatment of surgical failures suggests that muscle education and resistive exercise are indicated in all cases of urinary stress incontinence, either as primary therapy or as an adjunct to surgical intervention. Even in the presence of obvious structural defects resistive exercises should be instituted for an adequate period of time before resorting to operative procedures. In any case, nothing can be lost by such a plan, as physiologic therapy will not only improve function and tone of the tissues, but also their texture and tensile strength, thus facilitating surgical technic. In those instances in which primary physiologic therapy fails to relieve urinary stress incontinence, the complicating factor should be carefully determined and the surgical procedure best suited chosen accordingly. Regardless of the type of operation decided on, postoperative muscle education and resistive exercises will aid in improving function, tone, and elasticity of the tissues to enhance the surgical result.

PREVENTION OF URINARY STRESS INCONTINENCE

Urinary stress incontinence is recognized as a steadily progressive condition, but until now no *conservative* measures have been available to interrupt the physiopathologic process during its early stages. Physiologic therapy affords an opportunity to investigate and diagnose *early* manifestations of urinary stress incontinence. In the past, urinary stress incontinence was generally traced to traumatic incidents, especially during parturition, or to degenerative changes associated with the menopause, prolonged illness, and senility (Gainey). In the majority of cases of urinary stress incontinence, however, it is possible to elicit a history of earlier idiopathic dysuria, i.e., complaints of so-called bladder weakness dating from childhood, enuresis, nocturia, repeated attacks of urgency and frequency without apparent cause. These patients seem prone to recurrent cystitis in spite of adequate urologic therapy. When such complaints coincide with a finding of lack of awareness of function, and atrophy of the pubococcygeus, they can often be relieved through muscle education and resistive exercise. It may be concluded that this syndrome represents a predisposing status for the subsequent occurrence of overt urinary stress incontinence developing under the influence of such precipitating factors as trauma and degenerative changes.

Prophylactic physiologic therapy, therefore, is indicated whenever patients approaching childbirth, pelvic surgery, or the menopause present early signs of urinary stress incontinence or a history of idiopathic dysuria combined with dysfunction of the pubococcygeus muscle. While valid statistical data on the prophylactic effect of physiologic therapy are not yet available, early results, especially

The 19th century was characterized by more determined efforts to control fractures. John Kearny Rodgers, in 1827, used wire loops on the shafts of bone and Malgaigne introduced his adjustable metal hooks for treatment of fractured patellae. Hansmann introduced the basic idea of the bone plate fastened with screws in 1866 (Fig. 1). The metal from which the bone plates were made was varied by different surgeons. Steel, brass, bone, ivory, and other substances contributed to the fixation devices. The use of bone plates in the 19th century was basically the same as in the 18th century, as they were used only on compound fractures.

The beginning of the 20th century was noteworthy for the efforts of Lambotte to introduce internal fixation in closed fractures to improve the reduction of the fragments. William Arbuthnot Lane devised his steel plates (Fig. 2) and William O'Neill Sherman sponsored internal fixation by means of steel plates of his design made of vanadium steel. The progress in roentgenology, in aseptic surgery, and the means to retain fractures in satisfactory reduction offered a solution of difficult cases which was enthusiastically accepted.

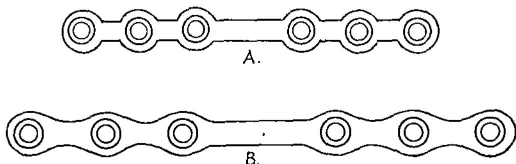


Fig. 2.—(A) Lane type of plate. (B) Sherman type of plate.

During this same period, efforts at fixation were not limited to plates. Wire, metal bands, brackets, bolts, staples, screws, clamps, rods, and probably every conceivable type of apparatus was suggested, used, or discarded, depending on the results and enthusiasm of the surgeon. Time has eliminated many of the devices but some remain for occasional use, especially wire and screw fixation in a limited domain.

Intramedullary fixation was not overlooked during this aggressive period of the first quarter of the 20th century. Hey-Groves used a steel pin in the medullary cavity of the femur to secure stability after reduction of the fracture. Later, the improved and practical intramedullary nails of Rush, Küntscher, Hansen-Street, and others were successfully introduced.

In reviewing the attitude of the first 25 years of the 20th century, one feels that all efforts were stimulated by the desire for complete immobilization. The tight screws and instruments to make wires and bands taut were typical of an intense desire to secure thorough fixation which seemed to permeate all surgical efforts.

Soon thereafter, internal fixation met physiologic difficulties. The tolerance of the human body to steel and other metals was found to be nonreceptive.

The Internal Fixation of Fractures of the Shafts of Long Bones

G. W. N. EGGERS, M.D.

INTRODUCTION

THE USE OF MECHANICAL devices to correct bodily deformities and to aid surgical procedures probably was initiated when man first endeavored to treat himself. The cycle included many devices and procedures crudely constructed but limited to external application of the affected part. The apparatus had extensive application in medical as well as surgical conditions as we consider them today, and it was only the logical sequence of events that in the surgery of trauma an effort would be made mechanically to reduce and maintain fractures in satisfactory positions. The early endeavors of internal fixation were restricted to exposed bone as in compound fractures, and these efforts soon resulted in controversy as to the propriety of internal fixation. As would be expected in the days before bacterial infections were understood, there were disasters which justified opposition to such procedures. Internal fixation remained in this surgical status during the 18th century.

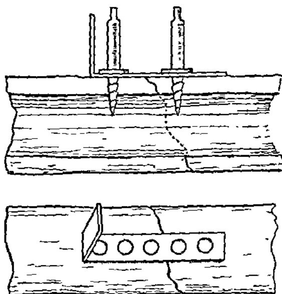


FIG. 1.—A drawing of Hansmann's original bone plate which was bent so that the end of the plate projected from the wound. Coarse-threaded screws were used with the ends also projecting from the wound. This was the first bone plate which was found to be practicable. (Drawn from Venable, C. S., and Stuck, W. G.: *The Internal Fixation of Fractures.* C. C Thomas, 1947.)

The healing process of bone differs in certain basic features from the soft tissue reparative processes. The final recovery of soft tissues is by mature fibrosis, whereas bone requires re-establishment of the structure from the basic cell to adult bone with complicated cellular changes, development, and mineral depositions. This complicated physiologic sequence of events proceeds in an orderly fashion unless disturbed or disrupted by constitutional or local variants.



A



B

FIG. 3.—(A) Nonunion with the Sherman type of plate. (B) Union after removal of the plate and skeletal traction.

The constitutional pathology of systemic diseases, congenital deficiencies, or of temporarily disturbed physiology requires recognition so as to permit, if possible, an intelligent correction of the condition. Pathologic fractures must be

Failure to secure the perfection sought, soon resulted in return to the closed method as the most desirable treatment.

Fortunately, the efforts to correct the previous difficulties continued. Many metals were studied, and the alloys which the metallurgists were creating received careful consideration. In 1936, Charles S. Venable and Walter G. Stuck *showed that the unfavorable reactions of bones to metals were due to electrolysis.* Masmonteil performed similar experiments in France about the same time. The ultimate result of these scientific investigations was to secure inert metals for the internal fixation of fractures. Vitallium, an alloy, and certain steel alloys were found to be relatively inert when used about bones in surgical procedures. No doubt this contribution will remain outstanding in the history of internal fixation of bones. Mechanical apparatus and physiologic tolerance of certain metals were approaching a logical interrelationship which would permit advances in the application of metals about and in bones.

Internal fixation gradually assumed greater importance in fracture treatment. Technic improved and results were better than ever before. The attitude, however, prevailed that to be successful surgical procedures should endeavor to secure complete immobility. This attitude of stability with immobility was strongly sponsored by many as the accepted fact. At the present time, it is still accepted by some of the surgical profession. However, in cases of immobility, the observation was made that certain fractures failed to unite for no apparent reason, or they did unite when the plate bent so as to allow bony contact and physiologic responsibility. Another pertinent observation was that if nonunion of a fixed fracture occurred, the simple removal of the plate to allow contact and compression of the fractured ends to occur resulted in union of the fracture (Fig. 3). These observations consummated in treating fractures by internal fixation with a method which would permit constant contact of the fractured ends during the healing period maintained by the normal muscular forces. These same forces contributed interfragmentary compression to the fractured area and were in the physiologic muscular balance. The mechanical means by which this was accomplished was the internal contact splint which by limited fixation permitted longitudinal interfragmentary pressure and maintained a physiologic stability (see Fig. 9).

Internal fixation at the present time has approached a status which permits us to utilize material and methods which do not hinder the physiologic processes of osseous repair. The clinical and experimental evidence of contact and compression permits the evaluation that this basic principle is a favorable, sound, physical factor which is conducive to desirable physiologic accomplishments.

The objective of treatment of fractures is to secure an anatomic result and perfect restoration of function. The science of internal fixation is to render surgical physiologic assistance to the displaced fracture and permit a physiologic accomplishment. The desire to give immediate structural function to fractured bone by operative methods has by self-evident fallacies influenced unfavorably our attitude in the surgical treatment of fractures. All surgical treatment of fractures must be a *physiologic mechanical effort to permit osseous repair to progress to* completion in the affected bone. There is no artificial lasting substitute for true osseous union of a fractured bone.

done which indicated that such physical facts bear a definite relationship to healing processes of fractured bones. The investigative work was done on the parietal bone of adult rats.

The parietal bone of adult rats was selected because it is free from muscular attachments, and therefore any artificial physical forces applied would not be confused with any muscular forces exerted in the selected experimental area. A flap was cut (Fig. 4) and, by means of split rubber bands, the bone flap was compressed on either side as desired. After varying periods of time, the animals were sacrificed and the flap margins were studied.

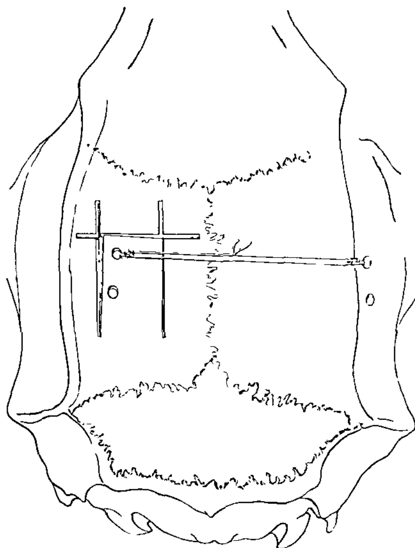


FIG. 4.—Enlargement of operative site, showing how compression is applied medially. Alternate compression point is indicated by extra drill holes.
(Eggers, G. W. N., Shindler, T. O., and Pomerat, C. M.: *J. Bone & Joint Surg.*, 31A:693, 1949.)

In this investigation, the margins of the flap which were under compression and contact showed marked osteogenetic activity or union. The margin of the flap which was not compressed did not show any effort of union. In addition,

recognized before any surgical relief is applied to the broken parts. The presence of debilitating disease, anemia, vitamin deficiency, protein insufficiency, and improper diet, as well as other constitutional disorders, must receive consideration and correction. Before a satisfactory local response can be anticipated in fracture healing, the constitutional contribution must be stabilized to the accepted normal state as medically evaluated by our present standards. When this is achieved, then our efforts must be applied to the local problem. It may be necessary to treat the patient simultaneously for both his general deficiencies and his local osseous trauma.

The microscopic appearance of the repair of fractures by histologic methods has been studied by many, and the appearance of the cellular activity and of the progressive formation of adult bone is basically accepted by the profession. There are differences of opinion as to cellular participation and the influences of the chemistry at the local area, but the reparative process is fundamentally dependent on the creation of a new structure influenced by circulatory, chemical, and physical factors. These factors must be favorably maintained, and any surgical procedures contemplated must respect and utilize the necessary physiologic and physical components.

The surgical treatment of a fractured area must therefore preserve the circulatory status of the affected parts. This is accomplished by avoiding methods which remove the periosteum or muscular attachments, depriving the bone of the circulation received from such sources. Particular care must be exercised in preserving the main arterial vessels which enter and are distributed to the bones.

We have no specific approach to altering the chemical processes in the local fracture area. The reaction of the hematoma and the physiologic processes can be approached only by maintenance of a good constitutional condition. This is accomplished by diet, transfusions, and maintenance of fluid balance, normal protein, and related chemical levels. The active contractions of the musculature of the affected and adjacent areas contribute with their circulatory stimulating effect ("accessory hearts") and the maintenance of bone responsibility, diminishing the decalcification of disuse atrophy.

The physical factors affecting the fractured bones are the restoration of alignment, contact of the fractured areas, and creation of mechanical situations which favorably influence the physiologic healing processes. This is accomplished by physiologic stability, which means that the fractured ends should be stabilized so as to prevent abnormal shearing motions and at the same time to permit the fractured surfaces to come in contact and be held there by the compression forces maintained by the muscles. The well managed closed reduction has physiologic stability established by proper treatment. When all factors are equal, the closed reduction should be the method of choice.

The purpose of internal fixation is to secure the benefits observed in the closed reduction. To accomplish this requires an understanding of the response of bones to the physical forces of contact and compression. To achieve the requirements which clinical observations show to be necessary, there was instituted a method of internal fixation by means of the contact splint or slotted plate which permits longitudinal migration, and at the same time provides stability. In order to determine the real value of compression and contact, experim

the control area not subjected to compression or contact did not present any active effort to repair the surgical fracture. The margin could be selected to unite at will and since the response was constant, we were *impressed that the contact-compression factor*, as the force was called, had a beneficial influence on the healing of bone. Therefore, the contact-compression factor is the combination of contact and the force to promote contact exerted on bone structures for which osseous union or osteogenesis is desired.

Figures 5A-C show an experiment in which the contact-compression factor has been applied for 17 days to the lateral margin. The lateral margin has united under the influence of the factor, the medial margin has not united.



FIG. 5C.—Medial cut (× 120). There is fibrosis and no union of the medial fracture margin. (Eggers, G. W. N , Shindler, T. O., and Pomerat, C. M.: *J. Bone & Joint Surg.*, *31A*:693, 1949.)

In Fig. 6C, the medial margin of the flap has received the benefit of the contact-compression factor and has united. The lateral margin, having no contact-compression factor, shows no effort to unite. The undisturbed skull margin makes no effort to fill the fracture gap.

In Figs. 7A-C, the contact-compression factor was omitted and nothing was applied to influence the margins of the bone flap. In this case, there is no union even after a period of 94 days. Therefore, the complete absence of the contact-compression factor has resulted in nonunion.

Figures 8A-C represent control areas of a compression experiment. This non-compressed control area in an animal in which the experimental flap was compressed shows no osseous activity to close the fracture gap.

In our work, we observed that too much pressure caused necrosis of the bone. We found also that even though an area was infected osteogenesis occurred in the side where the contact-compression factor was applied.

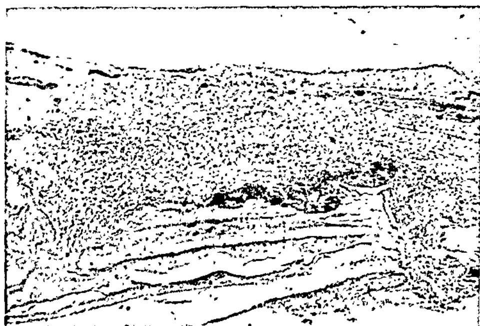


Fig. 5A.—Seventeen days (× 35) Lateral contact-compression factor was applied. Contrast the osseous union on the lateral aspect with the fibrous tissue in the fracture gap on the medial side.



Fig. 5B —Lateral cut (× 120), showing union of the lateral margin.

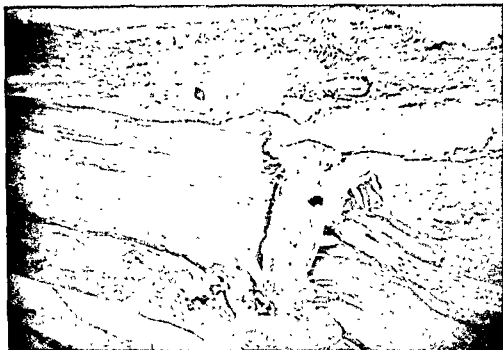


Fig. 6C.—Medial cut (× 120), showing osseous union of the approximated margins. (Eggers, G. W. N., Shindler, T. O., and Pomerat, C. M.: *J. Bone & Joint Surg.*, *31A*:693, 1949.)

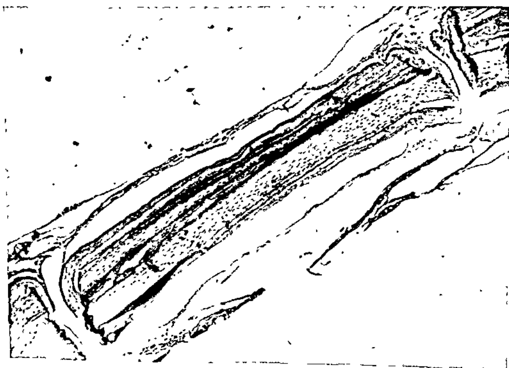


Fig. 7A.—Ninety-four days (× 35). No contact-compression factor was applied. There is non-union of the medial and lateral margins.

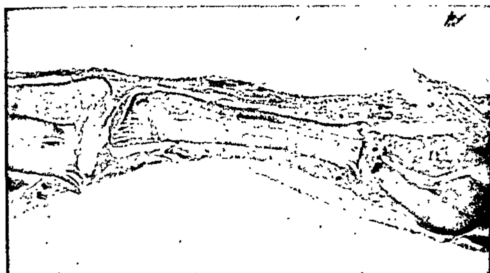


Fig. 6A.—Thirty-nine days (× 35). Medial contact-compression was applied. Osseous union has occurred on the medial side; there is nonunion of the lateral margin.



Fig. 6B.—Lateral cut (× 120). There is nonunion. Osteogenesis is present, with no purposeful effort to fill the fracture interval from the lateral skull margin.



FIG. 6C.—Medial cut (× 120), showing osseous union of the approximated margins. (Eggers, G. W. N., Shindler, T. O., and Pomerat, C. M.: *J. Bone & Joint Surg.*, *31A*:693, 1949.)

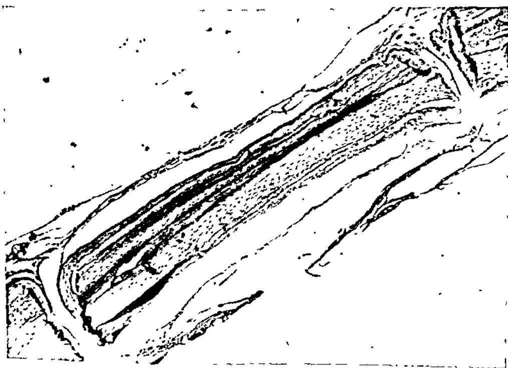


FIG. 7A.—Ninety-four days (× 35). No contact-compression factor was applied. There is non-union of the medial and lateral margins.

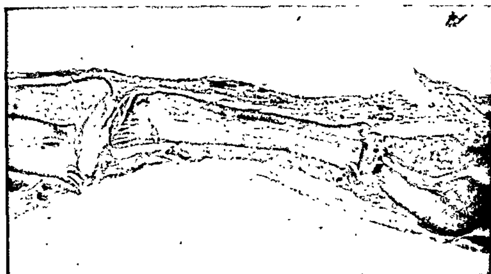


FIG. 6A.—Thirty-nine days (× 35). Medial contact-compression was applied. Osseous union has occurred on the medial side; there is nonunion of the lateral margin.



FIG. 6B.—Lateral cut (× 120). There is nonunion. Osteogenesis is present, with no purposeful effort to fill the fracture interval from the lateral skull margin.

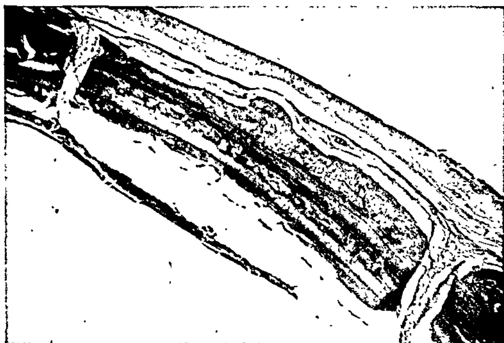


Fig. 8A.—Sixteen days (× 35). No contact-compression factor was applied to this area of the flap. No effort at union of the fracture margins is evident.

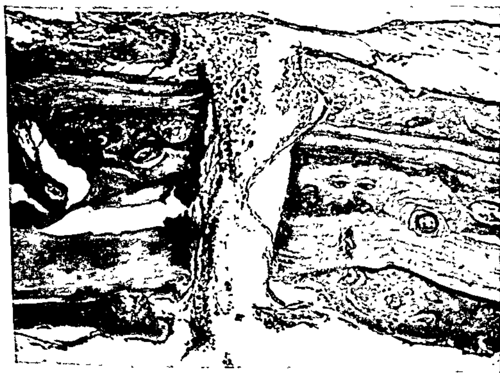


Fig. 8B.—Lateral cut (× 120). There is no purposeful osteogenesis for union.



Fig 7B.—Lateral cut (× 120). Lateral fracture margins are not united.



Fig. 7C.—Medial cut (× 120). The medial fracture margins are not united.
(Eggers, G. W. N., Shindler, T. O., and Pomerat, C. M.: *J. Bone & Joint Surg*, *31A*·693, 1949.)

the pressure as it will vary with the muscular mass and muscular effort of the individual. However, we are of the opinion the presence of the contact-compression factor is essential to good fracture treatment and must be utilized.

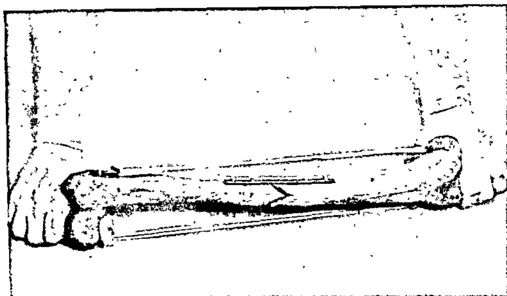


Fig. 9A.—Femur with contact splint applied. Longitudinal muscular pull is simulated by the use of rubber bands. The splint is not rigidly fastened, and traction shows how fragments will separate. Proper screw placement at operation prevents distraction.

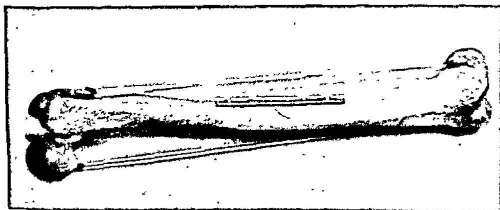


Fig. 9B.—Femur with contact splint applied. With traction released, the longitudinal pull with rubber bands opposes the fractured ends, maintaining them in apposition with contact compression during the course of healing.

The utilization of the physiology of muscular activity requires early restoration of motion which, while it produces interfragmentary pressure and improves circulation will also maintain joint activity. The perfect situation cannot always be accomplished, but an endeavor should be made to approach perfection.

The clinical application of the many necessary factors which will aid fracture healing must be recognized and used advantageously. An operative procedure using metals must utilize the inert alloys. When several parts are used, as plates

The clinical importance of the experimental work summarized above is that *the healing of bone is benefited by securing contact of the fractured ends and* allowing them to be under pressure and the pressure to which they are accustomed, we believe, is the optimum pressure of the individual affected. The fractured ends must not be distracted by excess traction or by fixation which prevents the compression forces from acting on the involved fracture surfaces. For many years, the surgical approach to fracture treatment has been such that when the fixation was accomplished a feeling of a completed procedure per se was accepted. *This is not so, and not until the bone has re-established its bony* continuity can the healing process be considered a physiologic accomplishment. No metal is a substitute for fracture healing.

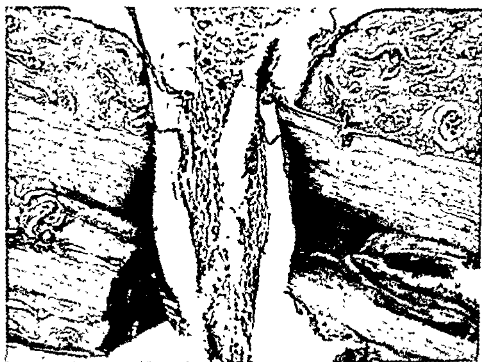


Fig. 8C.—Medial cut (× 120). There is no purposeful osteogenesis for union. (Eggers, G. W. N., Shindler, T. O., and Pomerat, C. M.: *J. Bone & Joint Surg.*, *31A*:693, 1949.)

To apply the principle of the contact-compression factor to clinical fractures required the revising of some of our previous concepts of operative fracture fixation. A method was devised to allow the fractured ends after reduction to remain in contact and the fractured ends to receive the contact-compression forces which the muscles normally exert on the injured bone. The fixation, allowing the interfragmentary pressure also, had to be such as to offer stability to the fracture. To accomplish this, the slotted type of plate or internal contact splint was devised. The principle of the fixation is to stabilize the fracture, and by not tightening the screws to permit longitudinal pressure on the fractured portion of the bones. The muscular forces produce this pressure by tone and muscular activity (*Figs.* 9A *and B*). We are unable to determine the mathematical value of

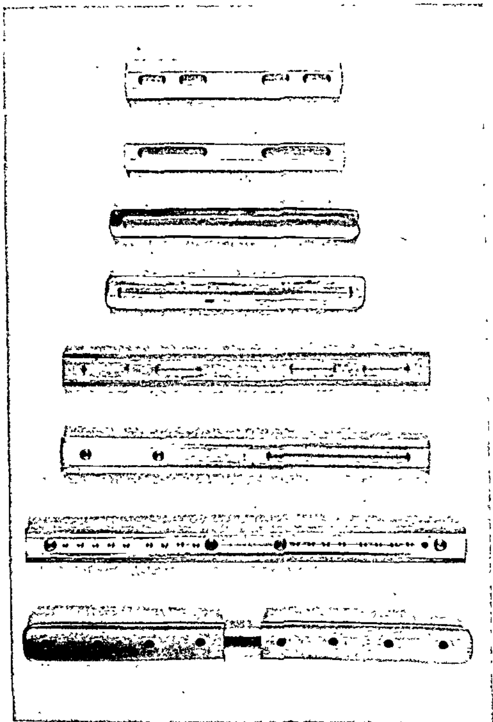


FIG. 10.—Experimental type of splints discarded. The upper two splints are 2 inches long and are too short.

and screws, it is absolutely essential that they be of the same metallic alloy to prevent electrolysis and the difficulties attendant thereto.

The length of the plate is important. This is especially true in practicing the contact and compression of interfragmentary pressure. The forces produced longitudinally on the shaft of bones are in many planes, because of the various attachments of the muscles producing the forces. This fact requires the splint or plate to be long enough to convert the longitudinal shearing forces into compression forces. A short plate cannot receive the proper leverage for such conversion of forces and is not desirable. One must use a long plate or splint in securing the proper stability for a shaft fracture.

The conversion of the forces acting on the fragments into longitudinal compressing forces is the principle of the slotted plate. As these forces act on the fracture fragments and oppose them, their obliquity locks the splint in stability and at the same time does not hinder opposing longitudinal migration of the fragments which may be necessary during the healing process. However, if these forces are not converted to compression and only a proportionately long splint will do it, the forces themselves become shearing in type which is not desirable or conducive to prompt fracture healing.

The plate must be strong enough not to be bent by these divergent forces acting on it, and yet it must be sufficiently pliable so that it can be made to conform to the surfaces to which it is applied. In this consideration, one must remember that no plate, splint, or intramedullary nail has been made which cannot be bent. This means that all of these devices are only aids in our work and that full responsibility of the bone occurs only when union is complete. There are great strains at the fracture site and sufficient time for healing must be allowed. The present status of commercial plates and splints is such that the article supplied is that which the manufacturer cares to produce. Most manufacturers are co-operative, but there is no way by which one can impose rigid measurements as to size, thickness, design, or engineering principles to a certain type of device. This is unfortunate because a few poorly manufactured articles may discredit a good method of treatment.

The contact splint is designed for a maximum strength for the width, length, and thickness. The basic construction involves the double L-beam principle for longitudinal rigidity and a heavy central portion increases the strength in the area of the fracture. There are two slots, one on either side, which permit a choice of placing the screws and also the number of screws. The single-slotted plate and the four or more oval slots were used in the early experimental work with the splint. The single slot was discarded because of the lack of strength in the central portion (Fig. 10). The many slots were discarded in favor of the two slots because the small amount of metal contributed little to the strength of the plate and too often the interslot metal covered the place for an additional necessary screw. Therefore, the superiority of the two-slotted plate resulted from clinical use and the other types have been discarded. Properly made, the two-slotted contact splint is a sturdy, well engineered piece of apparatus (Fig. 11).

The application of splints or plates may require conformation to a surface to which they will not fit without bending. The splint must therefore be of a metal which will permit bending (Fig. 12B). The steel and vitallium splints which

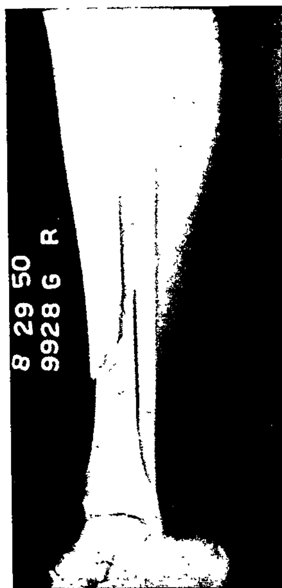


Fig. 12A.—Comminuted fracture of the right tibia.

The length of the screw is important. It should pass through both cortices of the bone (Fig. 13) and extend through sufficiently for complete engagement. It is undesirable to have screws projecting any great distance beyond the bone. This requires proper length of screws or a cutting instrument to shorten long screws. Short, one cortex screws are not good except in oblique fractures where it is impracticable to use a long double cortex screw (Fig. 14). Properly placed, several short screws in combination with a long screw can give remarkable stability. Their use is condoned in certain situations.

The anticipated prolongation in the healing period of most compound fractures must be carefully evaluated. Early muscular activity and, in weight-bearing bones, partial or light weight-bearing are useful adjuncts to the healing process. Early full weight-bearing is not recommended because excessive interfragmentary pressure may result in detrimental necrosis of the fractured surfaces of the bone

are available can be bent but, as would be necessary for a good splint, the bending can be done only with the plate benders and requires considerable force. It is best to evaluate carefully the bend required in a plate and accomplish it in one effort. Repeated bending of a plate is not beneficial to the internal structure of any metal and should be avoided.

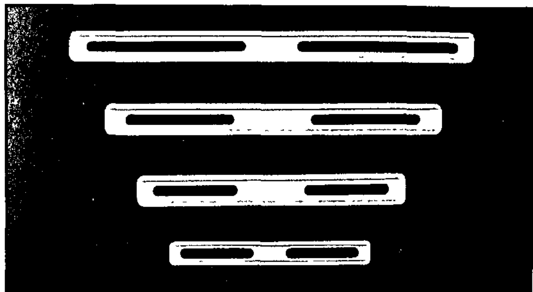
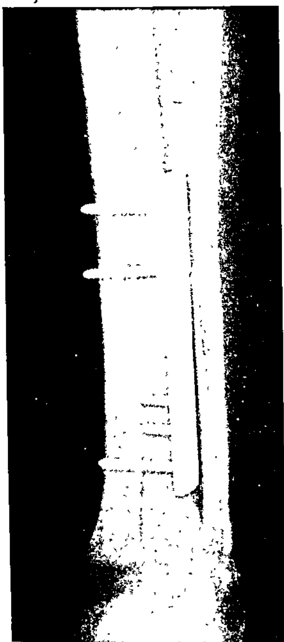


Fig. 11.—Contact splint, 6, 5, 4, and 3 inches in length. (Eggers, G. W. N. et al.: *Arch. Surg.*, 62:467, 1951.)

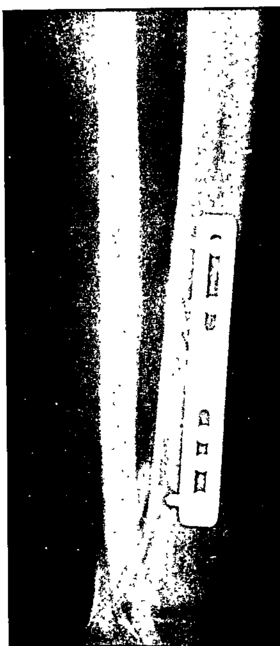
The application of the splint to the bone is important. The splint should fit snugly but should not press against the structures with destructive force, nor should it bind or prevent interfragmentary pressure. A flat surface is desirable for this. It *is undesirable to make a splint curve to fit the entire area of the shaft* which it covers. This is due to the fact that all long bones are not mathematically straight nor their arcs of curvature a mathematical repetition. Therefore, a flat surface causes less local pressure, fits well on the many curving areas, and does not hinder opposing longitudinal migration of the fragments. The ends of all splints or plates should be beveled and sharp corners are to be avoided. This is not too important but makes for a smoothly fitting contour.

The question as to what type of screw should be used to fasten the splint or plate is still being debated. The depth of the thread on the screws, the number per inch, the type, the shape of the head, and many other features are praised or condemned. There are reasons for such attitudes. Many screws are inadequately made, and *in plate and fracture work the well constructed screw is essential.* The heads of some screws are soft and these should be discarded; in others, the slot for the screw driver is inadequate. There are other deficiencies which the manufacturers have recently eliminated, and the lack of good strong screws has gradually decreased. The screws should be self-tapping and fit well into the hole bored to receive them. The drill hole should be small enough to engage the screw securely. The success or failure of an open reduction often is dependent on good unbreakable screws well engaged in the bone.

or bending of the splint. Reasonable means to promote recovery should be utilized to the best advantage.



A



B

FIG. 14.—Oblique fractures of the tibia showing the use of long (A) and short (B) screws in the distal fragment.

The administration of the antibiotics is routine in all surgery of fractures except those with severe allergic responses. All fracture surgery results in a wound which will accumulate a certain amount of serum and the bone ends may slowly ooze and form hematomas of varying proportions. Many muscular areas have small-pooled blood accumulations, and in compound fractures this

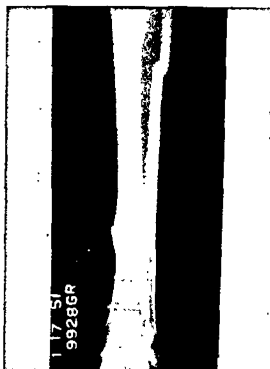


FIG. 12B.—Four months and 19 days after application of the contact splint. The splint was bent to accommodate the lower shaft of the tibia. Osteotomy of the upper one third of the fibula to allow compression forces to act. The patient is walking on the leg with satisfactory union.

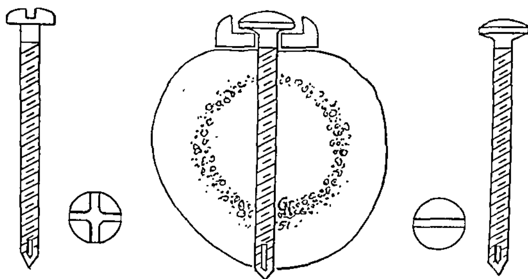


FIG. 13.—Types of screw heads. The screws must go through both cortices of the shaft.

Fresh compound fractures are always a problem requiring the best judgment and careful technic of the surgeon. These fractures require the careful débridement of a potentially infected wound and exposed bone. The preparation has been thorough cleansing of the affected part with soap and sterile water, followed by careful removal of devitalized skin margins and soft tissues. Attached bone fragments are not removed and larger detached ones are retained. The wound is cleansed with soap and water and then thoroughly irrigated with sterile normal saline solution to complete the mechanical cleansing. Sclerosing antiseptics should be avoided because of soft tissue coagulation. The soap and water cleansing is repeated until the wound is considered mechanically cleansed, within all human possibilities. After this process, the extremity is redraped and with fresh instruments, the operators having changed gown and gloves, the final ritual of cleansing is considered completed.

The problem in these cases is whether or not to use internal fixation. The question cannot be answered definitely. Internal fixation is certainly a boon to the problem, and we feel that, if possible, the procedure should be done. Good technic and the availability of the antibiotics have improved the possibility of securing a noninfected wound. If internal fixation is not deemed advisable, the wound is closed and treatment is instituted by cast or traction as the case demands.

The skin closure is important in compound fractures and no bone should be left exposed if it can possibly be covered. If necessary, relaxing skin incisions (Fig. 15) and/or sliding skin grafts should cover the exposed bone. The after-treatment is the same as that for any postoperative fracture case: antibiotics, tetanus antitoxin, plaster splint, cast, or balanced traction.

The healing period of bone in compound fractures, we find, is longer than that in closed fractures whether or not they are treated by internal fixation. This is probably due to the extensive trauma of the soft parts and severe injury to the bone. Our experimental studies demonstrated that exposing the bone ends outside of the wound delayed the healing response. The circulatory effect on the bones may also be great from vascular damage or the contracted vessel spasm of trauma. Transverse and oblique wounds also cause lymphatic stasis distal to the wounds and hamper the return to the normal physiology of the damaged area.

All fractures require good roentgenographic studies of the involved area. Any shaft fracture demands a roentgenographic study of the entire bone, including the joints proximal and distal to the fracture. One may find fractures not anticipated and avoid embarrassment later.

The careful consideration of a fracture is absolutely necessary first to determine the method of treatment and, if internal fixation is to be performed, the surgeon must be well informed of the problem to be solved. He must be aware of the angles of the fractured ends, the presence of fragments, large or small, the presence of longitudinal fractures, loss of small fragments from the fractured ends decreasing the fracture surface to contact, and the disposition of comminuted fragments. The size, shape, and replacement of any large fragment and the method of retaining the fragment in position can be reasonably determined preoperatively. A well informed surgeon is a better surgeon.

The postoperative interpretation of roentgen films of the fracture site requires

condition is quite evident. It is essential to administer the antibiotics in large doses preoperatively so that any static wound fluids will have a high level of antibiotic activity. These pooled areas cannot be reached by postoperative administration of antibiotics.

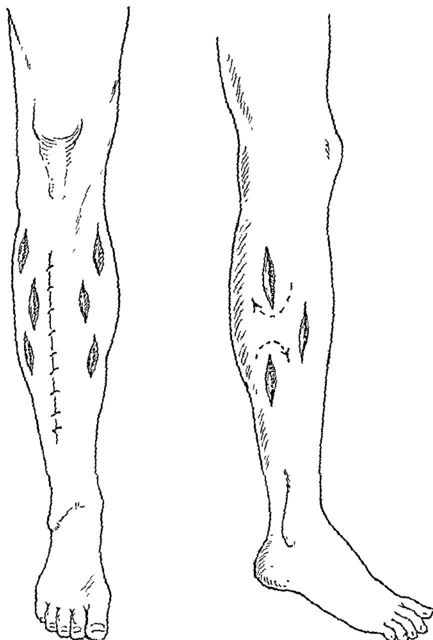


FIG. 15.—Relaxing skin incision, staggered to allow circulation as indicated by arrows. These incisions may be longer if necessary.

Postoperatively, the administration of penicillin, streptomycin, terramycin, and related antibiotics is necessary to give the patients the benefit of their ability to hinder bacterial activity.

In contrast to the healing "per primam" and the ossification of the callus, one may see *excessive bone formation at the fracture site*. This may become proportionately large and is the result of shearing forces. Union may occur but is usually delayed and a careful survey generally shows the lack of controlled compression and contact of the fractured ends. The bone formed in these cases generally closes

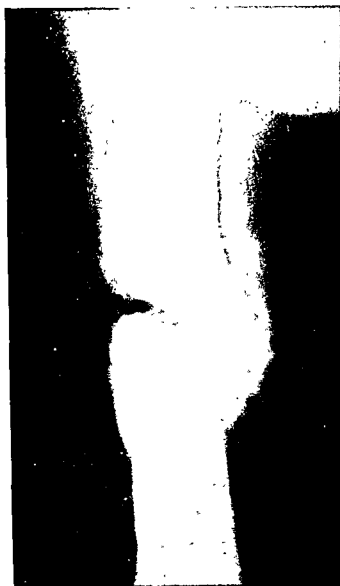


Fig. 17.—The formation of hard avascular bone (keloid type) due to efforts of complete immobilization which failed and permitted shearing forces at the fracture site and resulted in nonunion.

the medullary cavity, is excessive in type, and of poor quality. If cut with a chisel, it is marble-like with only a sprinkling of tiny pink spots because of the poor vascularity. This type of bony reaction we speak of as "keloid formation" (Fig. 17), in contrast to healing "per primam," and it indicates that the treatment has inadequately controlled the fracture ends. The quantity of bone deposited about

careful study and evaluation. The use of the term "callus" is so loosely applied that often it is difficult to understand what one actually means by it. The early formation of callus and the stabilizing effect especially when calcium is deposited should be the general connotation of the term, and such callus is particularly apparent in young people or often in severe closed injuries. The callus may or may not become ossified and participate in the bony union of the fragments. Much of the callus may be absorbed. When present, the callus may be useful



Fig. 16.—Most of the shaft healed per primam with little ossification of callus. Complete bony union 10 months postoperatively.
(Eggers, G. W. N. et al.: *Arch Surg.*, 62:467, 1951.)

in the bony fracture repair, but it must be clearly understood that the absence of an exuberant callus is no indication that osseous union of the shaft will not occur. In anatomic reduction of a fracture, little or no callus may appear, and the fracture will heal perfectly. Basically this has been referred to by Dr. Robert Danis as healing "per primam" (Fig. 16). Too often, this important fact is not appreciated and an unfavorable impression of healing is conceived and mistakes are made.

tern of the fractured ends is obscured by the overlying callus. We feel that the careful examination of the fracture margins in cases with little or no callus will often reveal satisfactory progress instead of a condition which may be discouraging to the uninitiated.

SCREW FIXATION

The internal fixation of shaft fractures by screws is particularly adaptable to long oblique or spiral fractures. Probably the tibia is the recipient of more screw fixation than any other bone. Screw fixation, if properly used, can secure good results. Here, again, screw fixation often does not accomplish the anticipated complete immobility which it is expected to secure. This is fortunate because it permits the musculature to compress the fractured ends effectively, not by desire but because of the mechanical weakness of the fixation.

The application of the screws should follow a definite principle. In the transverse fracture, it is difficult to apply the transfixing screws, and this procedure is not recommended. The screw should, if possible, be placed at right angles to the fracture line, but obviously, this cannot always be accomplished. It is absolutely impossible in a transverse fracture and often difficult in spiral fractures. The moderately oblique fracture permits screw placement at right angles to the fracture line.

The long oblique fracture permits usually a sufficient number of screws to secure stability but no immobility. No doubt the use of screw fixation alone can be satisfactory in certain selected cases, but the fracture site stability is much better when a contact splint is applied.

The type of screw is important when one uses it as a means of internal fixation. The drill hole must be made with the fracture in perfect reduction and this can be difficult in transverse fractures. If the drill hole is out of line, the fracture reduction will be distorted, and this is certainly not desirable. If the proper drill hole is made to bring the fracture margins together, it is desirable that the screw have a self-tapping point and that the neck be smooth. Thus, when the screw enters the opposite cortex, it can compress the fracture surfaces (Fig. 19). A

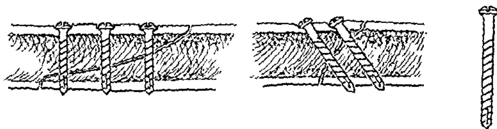


Fig. 19.—Types of screws and method of applying them at the fracture site.

full-threaded screw can only stabilize the opposite cortex at the distance between the fragments which is present where the threads engage. One cannot oppose the surfaces by progressively tightening such a threaded screw. The other alternative is to make the proximal drill hole larger than the one in the opposite cortex to permit nonengagement of the threads on the proximal side which produces the same compression effect as a nonthreaded screw neck. Thus, to get compression, one may have to sacrifice the stability of the screw in the proximal

fractured ends is no criterion of estimation of the quality of the healing which is taking place.

The new bone formed by shearing forces must not be confused with the ossification of callus which is a rather prompt healing effort and may form good striated bone as the healing process progresses (Fig. 18).



Fig. 18.—Ossification of callus resulting in good bone.

The roentgenographic evaluation of healing "per primam" can be understood by careful study of the film. The quality of the roentgenogram must be excellent. The fractured ends in these cases show no great callus formation nor is there any excessive osseous activity about the fracture. A careful inspection of the fracture sites does not show the sharp lines seen in the immediate postfracture film. The fracture margins have a fine longitudinal "feathery" appearance. This is due to the changes in the spike-like projections of devitalized bone which were demonstrated in serial sections of the fractured femur in the dog. This change produces a loss of transverse linear definiteness which in our experience is indicative of active bony union and is observed particularly in the cases which heal "per primam." If much callus is present in the fracture site, the detailed pat-



FIG. 20B.—The use of screws to hold large comminuted fragments in position as an accessory to the contact splint fixation. (a) Immediately after injury. (b) Four months postoperatively. (c) Thirteen months postoperatively.

cortex. The value, however, is that it permits a certain amount of compression force to the affected bone. Screw fixation is more stable than wire and consequently enjoys a more popular place in certain types of internal fixation. It does serve a useful purpose and should be properly applied in the cases selected. No doubt the long oblique or spiral fracture is the most desirable type of fracture for this method. In addition, this type of fracture usually heals more readily.

Postoperative cast support is necessary when fractures are maintained in reduction by the application of screws.

The use of the transverse screw as an adjunct to plate fixation has had a certain degree of popularity. Its use with the fixed plate indicates the weakness of the fixed plate in fracture treatment and an effort to overcome the deficiency by an accessory factor.

Screws alone or in conjunction with the contact splint are useful in maintaining larger fragments in position in comminuted fractures (Figs. 20A and B).

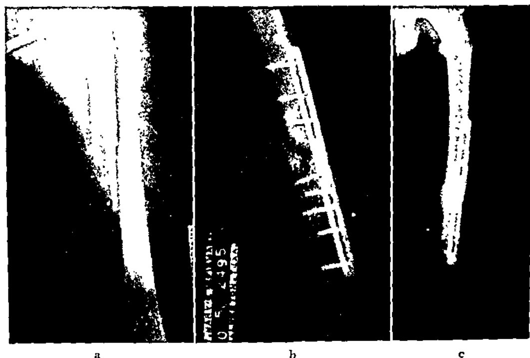


FIG. 20A.—The use of screws to hold comminuted fragment in position in conjunction with a contact splint. (a) Immediately after injury; (b) five weeks postoperatively; (c) four months postoperatively: satisfactory union.

WIRE

Wire as a means of internal fixation has been of service for many years. The use of this material has to a great extent been limited to the shafts of the smaller bones, such as the metacarpals and metatarsals (Fig. 21), but wire is also useful in maintaining comminuted fragments in position (Fig. 22) when treating the shafts of larger bone. The application of wire in fractures of the larger bones is one of personal choice.

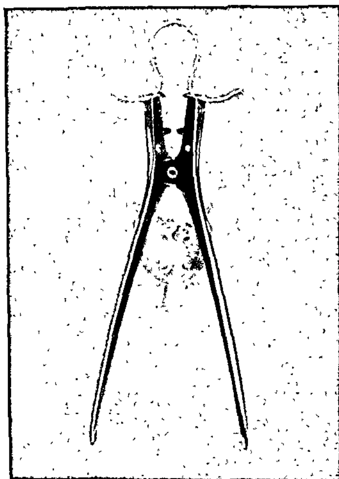


FIG. 23.—Wire tightener, Danis type.

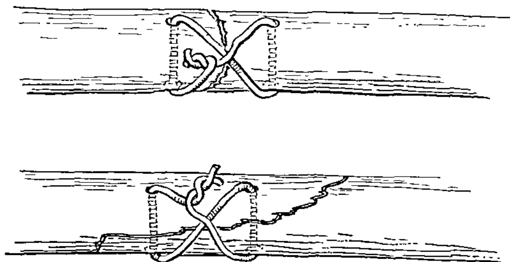


FIG. 24.—Application of wire to transverse and oblique shaft fractures.

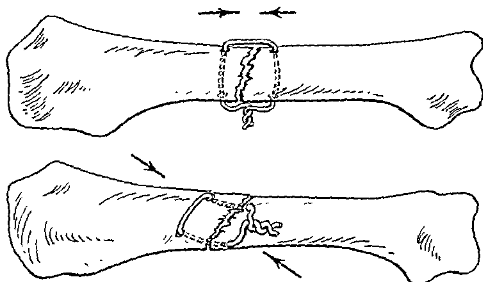


Fig 21.—Two methods of wire application for small bone shafts.

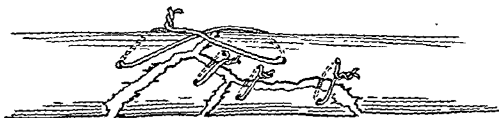


Fig. 22.—Multiple fragments held by wire fixation.

Stabilization with wire of a bone which has a great muscular pull is somewhat difficult, especially in a transverse fracture. Oblique fractures lend themselves to better stabilization owing to the mechanical obliquity and distribution of the fixation. A person may become quite adept at wire fixation and may achieve satisfactory results, but generally the method is not skillfully employed. Proper wire and wire-tightening instruments are necessary (Fig. 23). All bones treated with wire fixation require cast or balanced traction support until the healing process is completed.

As a rule, wire fixation does not immobilize sufficiently to prevent contact and compression forces from being effective and physiologically should not hamper bony union. Mechanically, wire fixation renders contact of the fracture but offers no leverage to convert shearing forces into compression forces. Thus, the wire fixation must be strong enough to withstand rather severe mechanical strain (Fig. 24). It is perhaps this feature and the necessity of accurate placement with the mechanical difficulties encountered which have made wire fixation of larger long bones unpopular. The surgeon in most cases feels a bit insecure, especially after he has experienced the breaking of wires which permit loss of his reduction.

There is no doubt in small bone shaft work that the use of wire is useful and that it provides a means of fixation in areas which are not adaptable to larger metal fixation. Wire fixation of the metatarsals and metacarpals, where indicated, is a useful procedure.

lacks length to convert shearing forces to compression. The internal contact splint utilizes muscular tone and contractions to secure its compression force in physiologic activity in contrast to the mechanical impaction of the coaptors.

Subsequent to the introduction of the slotted plate (internal contact splint) and method of application, permitting longitudinal migration of the fragments, many oval slotted plates have been offered by the commercial trade.

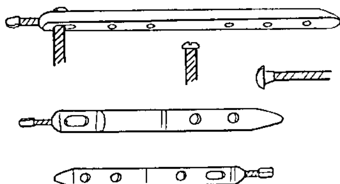


Fig. 26.—Coaptors and screws (Danis type).
(Drawn from Danis, Robert: *Théorie et pratique de l'ostéosynthèse.* Paris: Masson et cie, 1949.)

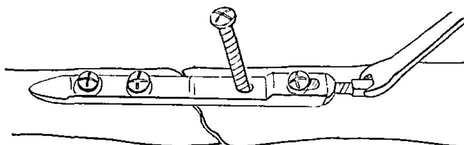


Fig. 27.—Method of applying interfragmentary pressure by a keyscrew with wrench. After compression is completed, the screw on the side of the compressing screw is placed and both are tightened.
(Redrawn from Danis, Robert: *Théorie et pratique de l'ostéosynthèse.* Paris: Masson et cie, 1949.)

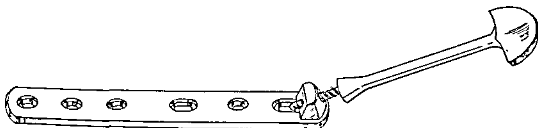


Fig. 28.—Venable coaption splint with removable coaptor.

APPLICATION OF BONE PLATES

Application of the metal plates of Hoffman and Lane was done with short screws which passed through a single cortex, and although these plates were useful they did not contribute a great deal of stability to the fracture site.

The Sherman type of plate with its many modifications, was much more stable, better constructed, and longer; and, with the introduction of placing the screws through both cortices of the bone, the fixation was more secure.

The vitallium and steel alloy plates produced many variations in construction such as the Venable and Townsend-Gilfillan types, L-shaped plates, and many modifications of the Sherman type of plate.

The common purpose of all plate fixation was to secure immobility. The degree of immobility obtained was not always as perfect as desired and perhaps contributed unwittingly to the success of the method. That this method had a definite weakness is evidenced by the effort of its proponents to add transfixing screws across the fractured ends to create a more rigid fixation. The idea of rigid immobility permeated all internal fixation and is still championed by some (Fig. 25).

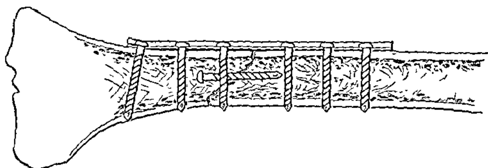


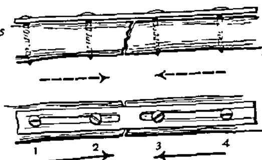
FIG. 25.—Application of plate for complete fixation, including the transfixing screw. This was the method advocated by Murray. The plate was screwed tightly to the bone.

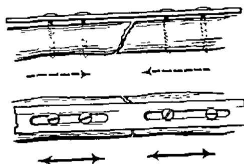
Rigid fixation became even more paramount in the surgical treatment of fractures, and we find rigid multiple plate fixation and also devices for dual fixation as those by Key and Wenger.

The next period of plate fixation resulted from the study of nonunion in rigid plate fixation and the correlation of the failures with the basic physical treatment of closed reduction. Following the principle of interfragmentary pressure of the closed reduction, which allows the fracture fragments to oppose themselves, the slotted plate (contact splint) was introduced (Fig. 11). Supported by clinical success and experimental confirmation, the method merits approval.

The coaption splint (Fig. 26) of Robert Danis must be mentioned as a method of producing mechanical compression with rigid fixation. This method produced artificial impaction by means of a screw (Fig. 27) and secured interfragmentary pressure. Venable has subsequently designed a coaptor which is a modification of Danis in that the impacting device is removable (Fig. 28). Henrick Söiland designed a slotted plate "20 per cent lighter than the Lane plate." This plate allows interfragmentary pressure but apparently is not structually very long and

The amount of the cutting area also varies. If the cutting portion is limited to the distal portion of about ½ inch, it has the advantage of not enlarging the proximal drill hole when the opposite cortex is drilled. Holes made with hand drills are slightly less in diameter than if an electric drill were used: for instance, for most screws a ⅛ inch bit is satisfactory if a hand drill is used; if, however, an electric drill is used for the same size screw, a 7/64 inch bit is much better.





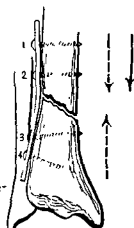


Fig. 29.—Placement of the screws.
(Eggers, G. W. N.: *J. Bone & Joint Surg.*, 30A:115, 1948.)

To avoid breaking bits, it is first necessary to have the fragments firmly held. If the fragments move, there is a danger of bit breaking because the fractured end usually moves in an arc owing to stability of the joint end of the fragment. This curved movement against a straight bit will break or bend it. A second factor is drilling the hole in the opposite cortex. When the drill engages the medullary

CONTACT SPLINT APPLICATION

The application of the contact splint is usually the method of choice. The procedure requires careful aseptic technic and proper local preparation of the patient. The involved extremity is well cleansed and shaved before the patient is taken to the operating room. Because of the pain factor, we often defer the preparation until the patient is anesthetized. The extremity is shaved, thoroughly cleansed with soap and water, and an acceptable antiseptic is then applied. The extremity is covered with stockinette, and placed on the usual sterile sheet covering. Sterile gloves and gowns, if worn by the surgeons in preparation of the patient, are discarded and fresh ones acquired for the actual operative procedure.

The stockinette is cut in the direction of the skin incision. The skin incision is made and then the stockinette is clipped or sutured to the skin margins to prevent introduction of infection from the skin areas. If skin clips are used, they should be counted before and after operation, so that none is lost in the wound to appear later in the roentgenogram.

As a rule, a tourniquet is not used. However, in leg and forearm procedures, a tourniquet should always be in place, readily available should it be needed. For the forearm, a blood pressure cuff is desirable. Inflation of the tourniquet is controlled by the anesthetist and a report is made at regular intervals to prevent prolonged use.

The application of the internal contact splint is limited to the shafts of the long bones, that is, the femur, humerus, radius, ulna, tibia, and fibula (seldom). The approach to these bones should be anatomic and preferably through intermuscular planes.

The drill holes should be placed so that they do not interfere with the longitudinal migration of the fragments. It is preferred that the drill hole at each end farthest from the fracture permit the screw to fit firmly against the splint and thus prevent distraction. The other screws are placed in advantageous places but none is closer than ⅛ inch from the central margin of each slot (Fig. 29). The number of screws depends on the type of fracture, the bones involved, and other local problems.

When the fracture has been reduced, the contact splint is placed parallel to the shaft. The solid portion of the splint covers the fracture site. The screws are then inserted and for convenience of working are firmly seated.

After placing all screws, the reduction, alignment, and contacting surfaces are checked for accuracy of reduction and when everything is satisfactory, all screws are given a half turn to the left. This will mobilize the fragments and permit the contact-compression factor to be exerted on the fractured areas of the bone. The screw release is important because it permits the longitudinal migration desirable for fracture healing.

The choice of drills is a personal one. The two basic types are the drills of tool steel and those of rustless steel (Fig. 30). The steel drills are more brittle than the rustless type. In fact, the rustless type of drill may bend and has the advantage of not breaking so easily. The disadvantage of the rustless steel drill is that it quickly loses its cutting edge. The drills can be reground if economy requires it.

What is the proper time interval after fracture to perform internal fixation? When a fracture is examined, and the roentgen study made, and in the judgment of the surgeon an open reduction with internal fixation is the method of choice, the procedure should be carried out immediately. The soft tissues have not become edematous and reduction of the fracture can be performed more easily. The patient soon has the fracture immobilized and is relieved of much pain and of the shock-stimulating factors. However, because of other injuries or delayed arrival of the patient, the operative procedure may have to be postponed. Under such circumstances, an adequate splint or skeletal traction is necessary. Skeletal traction pins should not be placed in any bone on which surgery is anticipated. In deferred procedures, the condition of the skin due to the abrasions which are potentially infected may contribute to additional delay. The delayed internal fixation of a fracture requires careful consideration of the factors of edema and excessive hematomas. It is preferable to proceed, if possible, on the day of injury; if delay is necessary, surgery should be done on about the 10th day. Usually the extreme edema during the first 10 days makes operative procedures difficult or almost impossible. Traumatic blebs if not infected are no contraindication to a surgical procedure.

The choice of a screw driver is important. Many are offered in the trade, but the only sturdy ones are of a good grade of steel approaching tool steel in quality. Soft steel alloys bend and do not give satisfactory service. One good simple steel screw driver is a great asset in inserting the screws into bone.

Many bone clamps have been devised, but all have a limited use. The best bone clamp is a good pair of bone-holding forceps manipulated by a capable assistant.

The approximation of a maximum area of the fractured ends is of utmost importance. The fragment ends often suffer loss of small or larger portions of comminuted bone (Figs. 32 and 33). This occurrence can be detrimental if fair



FIG. 32.—Diagrammatic representation of loss of bone at the fracture site.

sized fragments are displaced in the soft tissues and not replaced or are lost out of the wound in compound fractures; for in such cases the approximating portion of one or more fracture ends is often spiked to even half or less of the diameter of the shaft. Where such bone deficiency is present in any fracture, grafts should be placed immediately to replace the loss of bone area. Iliac strips and cancellous bone are available for these cases (Fig. 34) and prevent a situation which would be conducive to nonunion. The preservation of proper continuity of bone is essential for good fracture treatment.

The replacement of fairly large detached fragments in the fracture sites requires careful observation. These large fragments often remain as devitalized bone and

side of the opposite cortex, it usually strikes a curved surface. If much force is exerted against the bit before it thoroughly bites into the surface, it may tend to slip on the curvature and break. Therefore, after drilling the proximal cortex, one proceeds slowly when he starts to drill the opposite side so that the bit will not break.

FIG. 30.—Rustless steel and tool steel drills showing the difference in the length of the cutting edge.

If a bit is broken in the bone, it is much better to remove it, if possible (Fig. 31). This can be done with various tools, all of which work on the same principle of drilling around the bit and removing it. Two reasons for removal are the electrolysis problem and the medicolegal angle of the situation. If a bit is broken and cannot be removed for some good reason, the patient should be so informed by the operator.

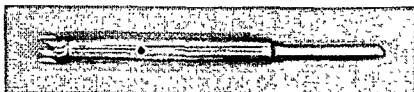


FIG. 31.—Wolferman drill and screw retriever. (Manufactured by Richards Mfg. Company, Memphis, Tenn.)

have in a roentgen film a more opaque or ground-glass appearance (Fig. 35). When this situation is present, one can expect a delay in the healing process, although union eventually will occur. Our observation is that this condition is more frequent in compound fractures in which the bone suffers great devitalizing trauma.

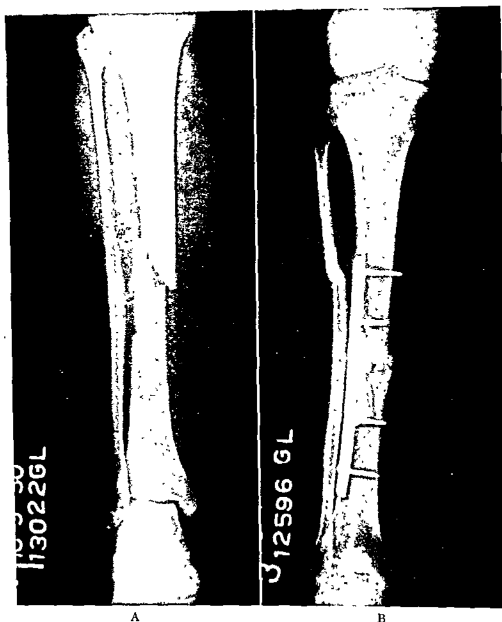


Fig. 35.—Comminuted fragment which failed to survive trauma. It appears opaque in the roentgenogram just under the contact splint. Union was delayed because of this condition.

The use of the contact splint in nonunion with or without grafts is of value in maintaining stability with interfragmentary pressure. It has the advantage in that it permits muscular and joint activity which would not be possible with the grafting procedure alone. We have found the splint helpful in our cases of nonunion.

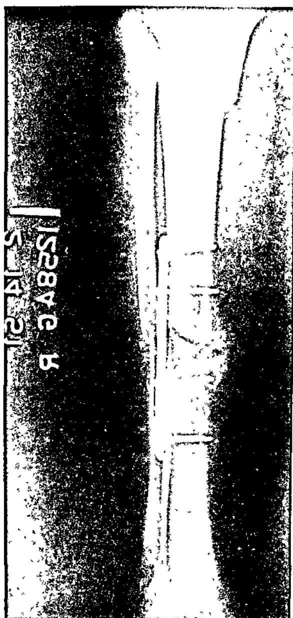


Fig. 33.—Loss of bone in compound fracture of the tibia. The gap should have been filled with cancellous bone at the time of operation. Result: union was delayed.



Fig. 34.—Loss of bone replaced with chip iliac grafts and onlay iliac strip to provide proper continuity of the healing shaft.

is vulnerable and should be isolated before proceeding with any splint fixation. It is rather easily found at the posterolateral edge of the deltoid.

The only support the humerus needs postoperatively is a sling. One may use a plaster splint temporarily for comfort, with the forearm and arm at right angles. If applied, it is discarded when the skin sutures are removed, and a sling is furnished. The patient is required to contract the muscles of the arm, and the exercise is taught by the surgeon. The forearm is not flexed during the muscular activity.

The contact splint used on the radius is 3 inches in length. The screws must be the proper length and not protrude any extent through the opposite cortex. As in all contact splint applications, the screws are not tight.

The radius is approached in the distal half between the dorsal border of the brachioradialis tendon and the lateral border of the tendon of the extensor carpi radialis longus. The superficial branch of the radial nerve is in danger when it passes backward beneath the brachioradialis tendon 3½ inches proximal to the styloid process of the radius. The abductor pollicis longus and the extensor pollicis brevis have to be retracted medially where they cross the radial extensors of the wrist.

The proximal two thirds of the radius may be exposed between the tendons of the extensor carpi radialis brevis and extensor digitorium communis. The supinator is seen covering the proximal half of the radius posteriorly. Proximally, the exposure may be extended by lifting the supinator from the bone with a periosteal elevator to preserve the dorsal interosseous nerve. Fractures involving the pronator teres insertion may require separation of the insertion from the bone in varying degrees. Careful reduction is necessary and any rotation of the radial fragments is corrected.

Fractures of the ulna are prone to delayed union and nonunion. A 4 inch narrow splint is best for the ulna. This bone when fractured is subjected to many varying muscular forces owing to the supinator, pronator teres, and pronator quadratus. For this reason, the longer splint is definitely preferable (Fig. 37).

The ulna is exposed along the posterior border. The skin incision must be over the muscular portion. Scars over bony surfaces later cause the patient discomfort. The splint should be well covered by the musculature and the fragments carefully reduced.

When both bones of the forearm are fractured, the same incisions and methods of exposure are used as for the individual bone fracture.

The routine postoperative treatment is a plaster posterior splint from midarm down to and including the wrist. The splint and sutures are removed on the eighth day and a circular cast is applied from mid-arm down to and including the wrist with the forearm in midpronation and at right angles to the arm. The thumb and fingers are free, and the patient is required to flex and extend the fingers to secure interfragmentary pressure (Fig. 38). The cast prevents supination and pronation because this motion is not desirable during the healing period. The healing process usually requires eight to 12 weeks.

The tibia is a large bone. Unfortunately, it is not surrounded by musculature as are the femur and humerus. Therefore, this bone is subject to great shearing forces at the fracture site, particularly in the lower third. The approach to the

Cases of nonunion in old compound fractures which have been infected and have ceased draining are successfully handled by the above method. The grafts are chip, onlay, or a combination of both. The onlay grafts are not fixed with screws, but if a massive onlay is necessary and fixation required, only one end is held firmly by a single screw, and this does not interfere with the contact-compression force.

When an old infected, nondraining case of nonunion is treated surgically, routine cultures should be made of the area and antibiotic spot plating of the organism done to determine the proper antibiotic to combat any possible reactivation of the dormant bacteria.

The humerus is probably treated less by open reduction than any long bone owing to the efficacy of the closed method with the hanging cast. There are occasions, however, when an open reduction may be the method of choice. When open reduction is performed, the splint should be carefully applied, usually on the posterior or anterior surface. The method of placement of the screws is shown in Fig. 29. This prevents any distraction caused by weight of the forearm. The large humerus requires a wide 4 or 5 inch splint; the small humerus, a narrow 4 inch splint (Fig. 36).

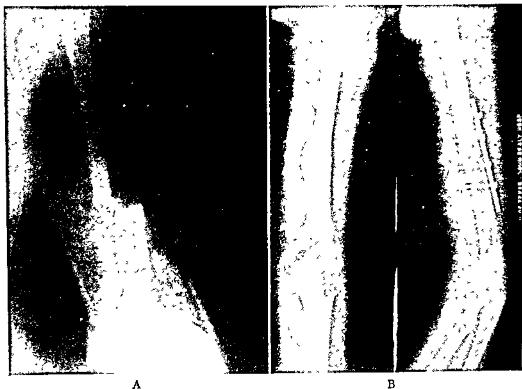


Fig. 36.—(A) Fracture of the humerus with interposition of soft parts and radial nerve paralysis. (B) Three months postoperatively.

The incision is on the posterolateral surface between the triceps and deltoid proximally, the triceps and biceps in the midportion, and distally between the triceps and the common extensor origins or brachialis muscle. The radial nerve

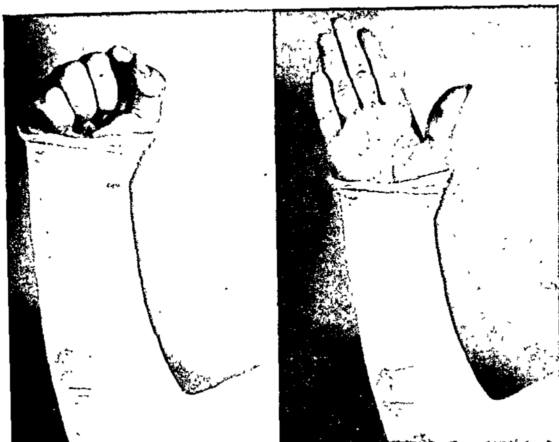
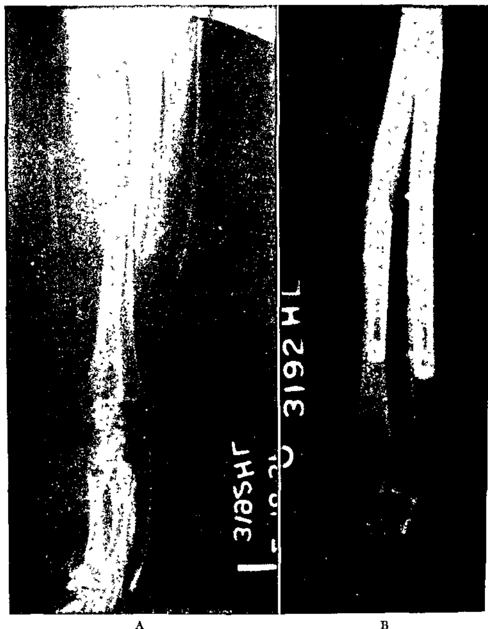


Fig. 38.—Cast for fracture of both bones of the forearm. Movement of the hand is permitted, but supination and pronation are restricted. The patients exercise their fingers and hand, thus compressing the forearm bones, and they are encouraged to use the hand as much as possible.

The fibula is usually not treated by internal fixation, but if required a 8 inch splint is adequate.

Postoperatively, a plaster splint is placed from the mid-thigh to the toes with the foot at right angle to leg. The skin sutures are removed on the eighth day and a circular cast is applied from the mid-thigh and extended to support the toes. The knee is in extension; the foot is at right angles to the leg, and a walking heel is incorporated at the time of application. The cast should be light but strong. The patient is allowed to rest the heel on the floor when he walks with crutches. After four weeks, weight-bearing is begun and is gradually increased. Usually, union is firm in eight to 12 weeks. It is imperative that the casted leg be no longer than the uninjured one. If necessary, the heel on the shoe of the good foot is raised. There is less shearing of the tibial fracture in weight-bearing if the knee is extended. Compound fractures require a long healing period, and occasionally a long-leg brace is fitted, if the healing time is obviously prolonged, to permit exercises of the knee.

When the open reduction of a tibia is delayed, there may be over-riding of the fragments because of muscular pull. It is often difficult to reduce the fracture because the traction application disturbs the distal fragment alignment. For these cases, a Kirschner wire traction temporarily applied through the calcaneus offers



A B

Fig. 37.—(A) Fracture of the forearm; a 3 inch splint was used on the radius and a 4 inch splint on the ulna. (B) Union satisfactory in eight weeks.

tibia is along the anterolateral surface and the incision should not be over the bone. A splint should never be placed on the anteromedial surface of the tibia. The fracture should be reduced and the splint applied carefully on the lateral tibial surface where it can be completely covered by the musculature (Fig. 39).

The length of the splint should be 5 or 6 inches to convert the shearing forces into compression. The 4 inch splint is seldom used alone on the tibia.

The screws are placed accurately and should be of the proper length. The splint should be bent, if necessary, to conform to the bone especially in distal and proximal fractures.

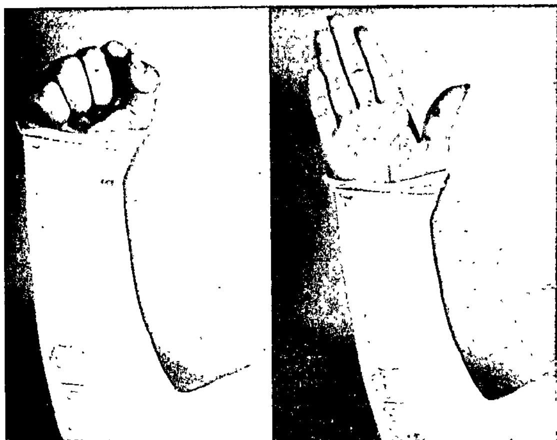


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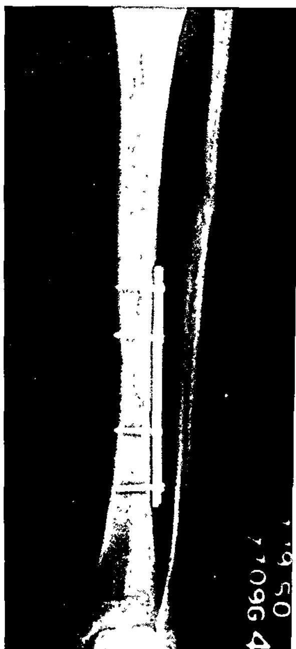


Fig. 39.—Application of the contact splint to the lateral side of the tibia.

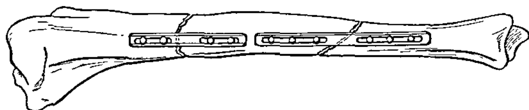


Fig. 40.—Method of applying two splints for double fractures.

much help in securing the reduction and allowing the distal fragment to be reduced more accurately. After internal fixation is secure, the wire is removed.

Occasionally, the tibial shaft may have two shaft fractures (Figs. 40 and 41). These are usually in the upper third and lower third of the bone. The proximal fracture generally heals sooner than the distal one. The distal fragment's impaired blood supply and less cancellous bone perhaps influence the healing process. In these cases, the application of the one splint will not suffice. The proximal fragment is held with a wide 4 inch splint and the distal fragment with a 5 inch splint. By combining two splints, one may have a splinting for 9, 10, 11, or 12 inches, if

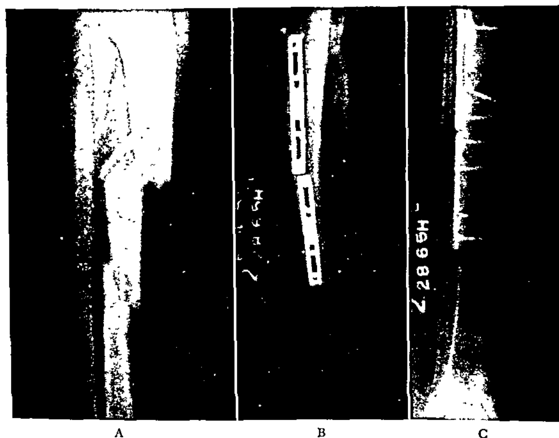


FIG. 41.—(A) Double comminuted fractures of the tibia. (B) Partial weight-bearing at 10 weeks. (C) Complete weight-bearing at 14 weeks.

desired. That is, for a 9 inch combination, use a 4 and 5 inch splint. The procedure is to fix the splint securely to the large loose fragment with tight screws and to allow the screws on the other fragments to be loose. Thus the fragment is compressed on both ends. This combination may also be useful on the femur.

The application of the contact splint to femoral fractures requires the usual care in accurate reduction and careful placement with bending to fit the contour of the bone if necessary. The surgical approach is posterolateral or lateral, as one chooses. The posterolateral is preferable as it permits retraction of the musculature without division of the structures. The posterolateral incision is difficult if one anticipates dual plating (Fig. 42) because the splint must be applied

anteriorly on the shaft and the exposure is somewhat restricted in relation to the anterior femoral surface. For dual fixation, the lateral incision is technically better.

The splints for the femur are preferably 6 and 5 inches and the 4 inch is used only in conjunction with other splints in the care of large separate fragments, such as those found in double shaft fractures.

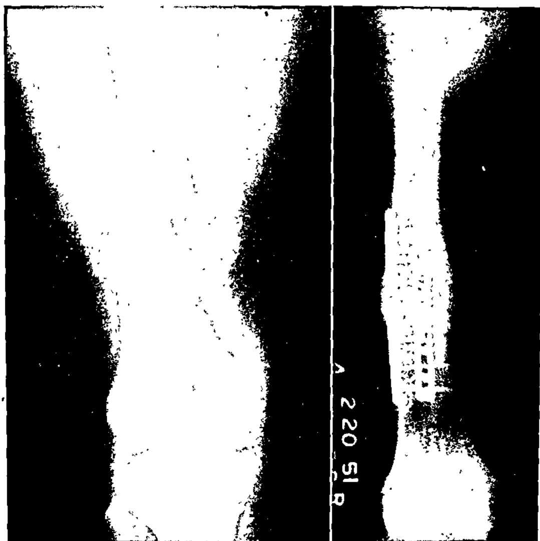


Fig. 42.—Dual splints applied in the usual manner allowing longitudinal migration. No supportive treatment, and motion was instituted early. Union and weight-bearing five months postoperatively. Weight-bearing was delayed because the tibia of the opposite leg was also fractured.

Comminuted fragments may be held in position with screws (Fig. 43) or wires.

Fractures near the distal end of the shaft, where the cortical bone is thin, usually require bending of the splint. In these cases, the portion of the splint which is bent and which lies on the distal fragment is securely fixed and longitudinal motion permitted by having the proximal slot screws loose. As one uses

the contact splint, he finds many technical ways of stabilizing and controlling fractures which result from the variation in fracture patterns.

The postoperative period in the care of fractured femurs is an important and critical one. The tendency too often is to perform the surgery, consider the reduction complete, and allow the progress to go unguided. The postoperative care of any fracture is important and controlled activity imperative in maintaining the function of the extremity.

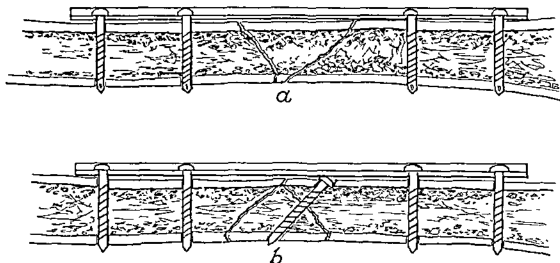
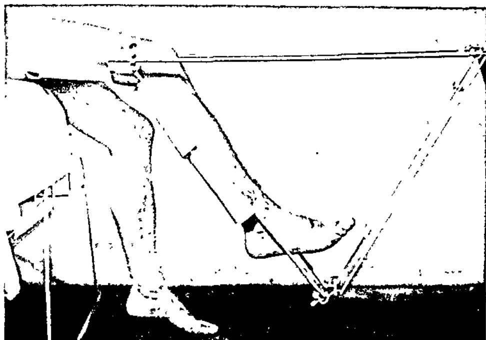


FIG. 43.—(a) Comminuted fragments held in position by the splint; (b) held in position by accessory screws.

The method followed for postoperative care after internal fixation is to place the lower extremity in balanced traction immediately after surgery. If bone traction was used previously, the same pin or wire is used; if not, skin traction is satisfactory. Within a few days, the patient is taught to contract the femoral muscles and after the removal of sutures this activity is increased. The traction is removed in about eight days and the extremity rests in the suspension splint. Extension of the knee is practiced and ankle motions maintained. After three weeks, the patient sits on the side of the bed and the knee is allowed to bend to 90 degrees (Fig. 44). The patient then flexes and extends the knee. This exercise is much easier to perform in the sitting position than in the supine and also presents much less strain on the fractured area.

The knee exercises can be accomplished by swinging the suspension splint at right angles to the bed and resting the end on a chair or table allowing the supporting ropes to hold it in position. Retaining the leg in the Thomas splint is for ease of handling. The greatest danger in handling a fractured femur which has been splinted is in moving the lower extremity with the knee extended. Allow the patient to flex the knee and the process is greatly simplified. If the patient has a stiff knee on admission, the problem is not so simple.

After a patient is instructed in postoperative conduct, he may continue the care at home, depending on the individual and the home conditions. Sitting in a chair or walking with crutches is usually not recommended until the eighth week because of possible accidents. The patient is then taught to stand on the



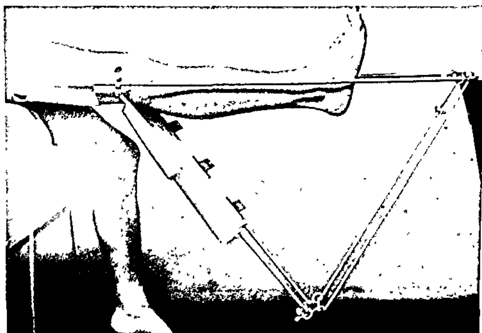


Fig. 44.—Flexion and extension of the knee three weeks postoperatively.

good leg and to strengthen the muscles for crutch walking. Light weight-bearing is permitted but the time for full weight-bearing depends on clinical stability and roentgenographic evidence of union. The activity permitted is greatly influenced by the patient's manifested sense of responsibility and understanding. When full weight-bearing is permitted, the fractured extremity should have complete ankle, knee, and hip activity, and the musculature of the entire extremity should be in good condition. Twelve to 16 weeks is the average time for full weight-bearing. The surgeon must convince the patient that his investment of time at this crucial period of treatment is worth his while.

The second half of the 20th century presents a new era in fracture treatment. The clinical successes due to the understanding of the relationship of metals and the utilization of the contact-compression factor to produce interfragmentary pressure assure the surgeon of osseous union. The results depend on attention to details of technic and functional maintenance. The continued use of the internal contact splint in all types of shaft fractures has secured bony union in over 95 per cent of the cases on first operative fixation. The remainder united after a second procedure, usually requiring grafting.

Greater accuracy in the treatment of shaft fractures is now demanded. Union of the fracture no longer suffices because the present evaluation of our treatment includes a return to normal function to eliminate any traumatic arthritis in the adjacent joints which may occur years afterward. There are some fractures which are so severe that restoration is impossible, but a broad survey of the problem requires union of the fracture and restoration of lasting physiologic function of the extremity.

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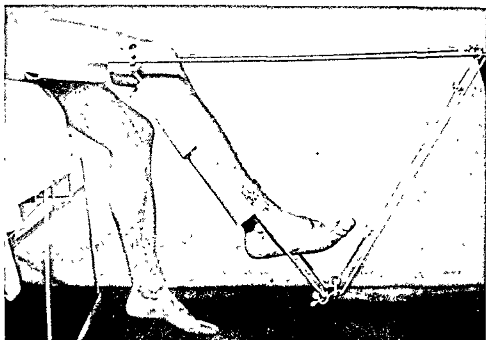
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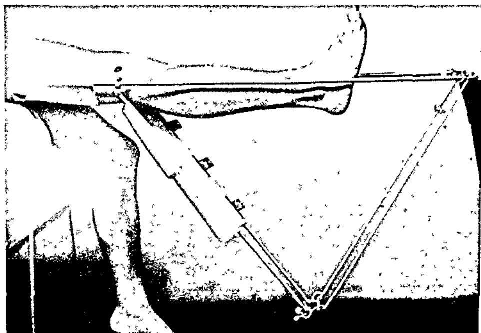


Fig. 44.—Flexion and extension of the knee three weeks postoperatively.

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Intracapsular Fractures of the Femoral Neck: Their Care and Complications

EDWIN R. SCHOTTSTAEDT, M.D., LOREN J. LARSEN, M.D., and
FREDERIC C. BOST, M.D.

INTRODUCTION

THE PROBLEM of fracture of the femoral neck is far from being satisfactorily solved. However, many advances have been made since the days when Royal Whitman initiated his drive for rational thought and positive care for sufferers from this injury. Before the days of Royal Whitman there were occasional individual surgeons who had an active approach to fractures of the femoral neck. The first recorded internal fixation was accomplished by Langenbach, in 1858, followed by Koenig and Trendelenburg. Lord Lister is credited with the first such procedure under aseptic technic. Martin of New Orleans, Albee of New York, and several others practiced operative reduction on occasion. However, no one made a practice of such surgical procedures. Royal Whitman successfully campaigned for an active program to give years of comfortable activity to those suffering from this injury. It was not uncommon at the start of his crusade to class all such fractures as untreatable, no positive attempt being made to seek union. It has been estimated that between 65 and 70 per cent of persons with fractures of the femoral neck were permanently crippled or died as the direct result of their fracture (Leadbetter). Whitman advocated manipulation and reduction held with a spica, applied in abduction, which locked the fracture reduction. The results with his technic varied in different hands, ranging from 53 to 90 per cent of union (Whitman).

The enthusiasm at the results of Whitman's treatment was so great that as late as 1936 Magnuson quoted Dickson and Dively, in a personal communication, as being opposed to open operation or nailing of femoral neck fractures since their results with Leadbetter's modification of Whitman's technic gave as high as 70 to 80 per cent of bony union, with a mortality of 5 to 15 per cent, depending on whether their patients were among the debilitated group in a general hospital or the more vigorous ones in their private practice.

In 1945 Leadbetter remarked that with the Whitman reduction and spica there was roughly a 33.3 per cent union rate, with a 26 per cent mortality. With the advent of his technic of reduction, which gave a better apposition of fragments, the percentage of union increased to 72.9 per cent with a decrease in mortality to 11.5 per cent.

It is thus apparent that great strides were being made from an unattempted treatment to an increasingly efficient method.

Smith-Petersen made the second great contribution in a method of handling these fractures when he introduced his three-flanged nail in 1925. As pointed out

earlier, this was not a new idea since open reduction had been practiced infrequently for many years by many surgeons, but the fixation device offered by Smith-Petersen was much superior to anything in use at the time.

The apathy which previously had surrounded this problem had been dispelled by Whitman. The tediousness of plaster care and long immobilization wore heavily on the majority of surgeons. The profession was ready and willing to accept a quick and easy technic that seemed to give good results and rapid mobilization.

In 1931 Johanson revived the extra-articular method of Nicolaysen which had been propounded as early as 1897, and the era of closed reduction and blind nailing was soon in full swing.

Many persons have added minor changes over the intervening years, but certainly no outstanding advance has been made.

The concept of primary osteotomy is perhaps the biggest recent step forward, for with it a positive approach is taken at the time of acute fracture so that we no longer sit complacently by waiting for a nonunion to occur in those fractures which seem doomed in advance to this complication. Thus, some nonunions are obviated while others are treated before they develop.

L. T. Peterson and others have used the Collision steel head and plate prosthesis of 18-8SMO stainless steel, and Judet and Judet are using a methyl methacrylate prosthesis reinforced with steel. These are principally recommended for late fractures or arthritis, though some few have been used in fresh fractures. Here the head fragment is removed and replaced by a prosthetic device. This represents an even more revolutionary idea but it is too early to evaluate the results. One cannot at this time recommend it for fresh fractures. Some results have been good, but there seem to be incompletely conquered mechanical defects. The ultimate fate of the prosthesis and adjacent bone cannot be determined at this time. In any event, such a replacement is, basically, sufficiently revolutionary to offer the stimulus for a more satisfactory solution to this difficult problem.

The following pages will deal only with intracapsular fractures of the femoral neck and will not in any way be concerned with intertrochanteric fracture or other injury about the hip joint. It is the purpose of the following paragraphs to point out a plan of treatment used by us with success, though not without complications. The number of complications have gradually decreased as we pay more attention to certain details in care. It is understandable that many of you who read the following will have a technic which satisfies you, and certainly there are many excellent and usable routines. No other fracture needs a routine plan for efficient care as much as do fractures of the femoral neck. We are opposed to an unalterable routine in the handling of any problem; however, it is of extreme value to have a basic plan to follow from the time of fracture to healing. The care of this fracture can in no way become haphazard, for all details must be carefully planned to give the patient every chance for a good result.

ABDUCTION FRACTURES

In only one type of femoral neck fracture can a definite prognosis be made at the time of fracture and before healing is complete; that is in the impacted or abduction fracture of the femoral neck. This occurs in abduction. Here the fracturing impetus forces the head and neck into an abducted position, impacting the fragments. The mechanism of injury is a fall on the hip or a glancing blow to the lateral surface of the hip with the patient in the erect position. The latter may be delivered by a passing car. The patient frequently falls to the ground, then picks himself up, limps to a nearby car and then to his doctor's office, complaining of pain but quite able to be about. Roentgenograms disclose the suspected fracture.

Linton has objected to the term impacted, preferring the term "stable fracture" (Fig. 1). It is true that not all of these fractures are impacted, though all are relatively stable. However, the type of injury and lack of displacement of the fragments at the time of injury make impacted a good term.



FIG. 1.—Typical abduction fracture requiring no reduction.

Care of such fractures varies greatly in good hands. Some surgeons place these hips in a single short leg spica. Others use well leg boots or a variation of this technic, holding the legs in internal rotation and abduction. Occasionally no immobilization is practiced, and, if the fracture is truly impacted, perhaps no harm will result. But if it is merely a stable fracture of this type—and one cannot always tell—we consider it dangerous to take these liberties since occasionally this type of fracture will lose its position and become displaced. It has been our practice, therefore, to nail abduction fractures as we do adduction fractures, though no effort is made to change the position if it should not seem anatomic at the time of nailing. Furthermore, the postoperative care after nailing is much

simpler than if the patient must be cared for with his legs locked together. With the fracture nailed, the patient is up and about within a few days, rapidly regaining motion and missing complications attendant on long bed rest and immobilization. When the fracture is treated in plaster, three months of immobilization are sufficient, with either limited or full weight-bearing following this, depending on the roentgen studies. In our group we have never found such a fracture insufficiently healed to bear at least partial weight at the end of a three month period. When the hip is nailed, the same plan is followed as far as weight-bearing is concerned. In three or four months, or at the most six months, the patient is walking again, bearing full weight without pain and with little or no limp.

In this fracture, because of the lack of displacement at the time of fracturing force, there is no disruption of blood supply by capsular tear. Contact of the fragments is excellent, and, therefore, healing progresses in an uncomplicated manner.

Linton described 2 cases with aseptic necrotic changes of the head. We have not as yet seen this complication with abduction fractures.

ADDUCTION FRACTURES

Adduction fractures of the femoral neck are an entirely different matter. Here, with rare exception, the fracturing force displaces the fragments, and frequently results in tear of the vessels carried in the reflected capsule of the posterosuperior and posteroinferior neck. In some instances the fracture is low enough or occurs in such a manner that the vessels are not injured. In any event, there is a loss of bony contact between the fragments, and reduction here is essential. Adduction fracture has occasioned heated discussions. No one can give any but a guarded prognosis for healing without complications when first viewing this type of fracture, though certain features of the fracture and the reduction help greatly in making a prognosis. This fracture occurs usually after the fortieth year, with the highest incidence in the seventh decade. Of course, there are occasional young adults, adolescents, and even children, but the average patient is close to 65.

Mechanisms

The usual story of the injury is that the patient has slipped and fallen. Frequently there is a rotary or twisting component to the fracturing force, though this is not necessarily true. Many of these patients speak of a blow on the hip. Falls on freshly waxed floors and throw rugs are common causes for this injury in older patients. Younger patients sustain the fracture on greater trauma, as automobile accidents or falling from heights—trees, roofs, or fences.

It has been often said that the patient fractures his or her hip and then falls. Certainly this does occasionally happen as when a sharp turn or pivot is made. We have one such patient who turned a corner suddenly, heard his hip snap, and then fell. However, this is not the usual mechanism of injury. Magnuson says that this ease of fracture in older people follows a natural senile osteoporotic and disuse atrophy of the main stress lines of the femoral neck. One of the best examples of an adduction fracture of the femoral neck known to me is the case

of a polio patient with paraplegia who was having his tensors stretched in adduction; as the therapist made the forceful adduction motion, there was a crack and immediate severe pain. Roentgenograms disclosed a typical femoral neck fracture, midcervical in location.

EXAMINATION

Immediately following the injury the patient lies with the injured leg in external rotation. Sometimes external rotation is a factor in producing the fracture, but more commonly the leg takes the position because of its weight. Usually the rotation is between 60 and 80 degrees; seldom is it at a complete 90 degrees because some of the capsular attachments at the base of the neck act to offer a limiting resistance to a more complete external rotation. Slight motion of the leg produces severe pain. The pain is not under the examining finger as it is in intertrochanteric fractures, but is usually anterior, directly over the joint. Direct pressure over the trochanter produces pain, but deep pain less superficial than that seen in intertrochanteric fractures. There is a loss of the dimple which normally marks the attachment of the gluteus maximus, and there may be some adduction of the leg with shortening. Edema is a later sign, appearing after a number of hours and is secondary to lack of motion from pain or from dependency. There is usually some early shock associated with this fracture, though the amount of shock present is usually not comparable with that seen in fractures of the femoral shaft. However, it may be sufficient to limit early care, making immediate operation impossible.

EARLY CARE

Before transporting the patient, the leg should be fixed in an extension splint; a Thomas's knee splint with padded ischial ring is most suitable. If this is not available, a long board splint extending onto the trunk or, as a last resort, the binding of the legs together with a pillow between the knees may be used satisfactorily. Where a type of fixation providing countertraction is used, application of tape to the injured leg and traction with a Spanish windlass is useful. In any event, prevention of unnecessary motion of the extremity is most desirable.

After the patient has been transported to the hospital, two lines of therapy are open, immediate or delayed surgical treatment. Much has been said about the value of immediate nailing, and we know there are some instances where it has been lifesaving; but as a general rule a delayed plan is perfectly acceptable.

It is our practice to nail these hips as soon as the patient is in suitable condition for the procedure, for we feel that it is to his best interest to have the procedure finished. While traction is painless and, if properly used, allows the patient freedom, certainly the period of recumbency is increased and postoperative discomfort is added to the confinement of a period of traction. However, when there is any doubt regarding the patient's general state, there is no reason for not delaying until the patient is in as good a condition as possible. We believe this period should not extend over two weeks. If for any reason operation must be postponed for six to eight weeks, some procedure other than nailing will almost certainly be necessary. It is true that patients can be cared for in traction throughout the period necessary to produce healing. This can be done either with Russell's trac-

simpler than if the patient must be cared for with his legs locked together. With the fracture nailed, the patient is up and about within a few days, rapidly regaining motion and missing complications attendant on long bed rest and immobilization. When the fracture is treated in plaster, three months of immobilization are sufficient, with either limited or full weight-bearing following this, depending on the roentgen studies. In our group we have never found such a fracture insufficiently healed to bear at least partial weight at the end of a three month period. When the hip is nailed, the same plan is followed as far as weight-bearing is concerned. In three or four months, or at the most six months, the patient is walking again, bearing full weight without pain and with little or no limp.

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the head of the Bell table. Use of the perineal post is an alternate method. Thus after reduction light traction can be placed on the leg, if desired, without allowing the patient to pull down on the table and off the cassette holder. The uninjured leg is splinted and bandaged with padded yucca board splints on either side of the leg from the knee to the foot so that it may be hung with the hip, knee, and foot at 90 degrees. The injured leg is manipulated, using either Whitman's maneuver of traction, to overcome over-riding and sharp internal rotation with abduction, or, more often, by Leadbetter's reduction. Here the hip and knee are flexed to a right angle and by lifting upward, with the surgeon's shoulder under the flexed knee, traction is made, and the weight of the patient's body is used for countertraction. The leg is jiggled in this position with abduction-adduction movements to allow the shaft to slide by the head. The leg is then sharply rotated internally, extended, and slightly abducted. We do not place our patients in extreme abduction and seldom use extreme internal rotation. We find that our reductions are more stable in about 15 to 20 degrees of abduction and 10 to 15 degrees of internal rotation. It has often been written that marked internal rotation is essential, but there are good studies to the contrary. Ellis Jones wrote that a simple transverse fracture of the neck of the femur could be easily and accurately reduced in a cadaver by abduction and internal rotation. A comminuted oblique fracture could not be accurately reduced; and if the fracture is from anterior to posterior in an oblique manner, extreme abduction and extreme internal rotation separate the fragments. He admits, of course, that such motions carried out on a cadaver do not necessarily prove a clinical point, though they are certainly suggestive. Linton remarks also that with fractures presenting compression of the posterior neck surface or marked comminution of the posterior neck, internal rotation frequently will leave a wide gap as seen on the lateral x-ray projection. In these cases marked internal rotation seems to be a factor in increasing the incidence of nonunion. However, some degree of internal rotation is essential to secure a satisfactory reduction.

When the leg has been placed in the leg-holder on the Bell table and tension is properly adjusted between the extensible footpiece and the sheet which is used for countertraction, the film may be taken in anteroposterior and lateral views to determine the completeness of reduction. Some have advised striking a blow at the upper level of the trochanter to cause a valgus impaction or abduction of the head. The blow, if struck, is not struck in line with the neck but at 90 degrees to the line of the neck. This maneuver is sometimes helpful, though I have never seen it cause impaction. It may aid in securing slight abduction; it may also occasionally displace the reduction. The hand-in-palm test suggested by Leadbetter to determine the completeness of reduction is useful, though not infallible. Some hips which are incompletely reduced will pass the test, while some which are satisfactorily reduced may not pass. In any event, it is a useful working method.

If the reduction shown roentgenographically is suitable, the hip is prepared and draped; if not, the reduction is redone. We use two portable x-ray machines, fixing their positions prior to draping so that the x-ray equipment need not be moved during the procedure (Fig. 2). Without an excellent reduction visualized in two views, healing cannot and will not occur. The reduction should show an

tion or straight leg traction in a Thomas splint. We feel, however, that this form of therapy is unsatisfactory and unreliable as to eventual healing. If traction is to be used as an interim mode of therapy, we prefer a modification of Russell's traction since this allows more freedom and comfort for the patient. If the patient is difficult to handle, tape traction on a Thomas splint is acceptable and more likely to be effective. The Russell modification which we have used is mechanically inferior to that described originally, but clinically it is easier to handle. The bed is placed on 6 to 8 inch shock blocks to aid in countertraction and to prevent the patient's being pulled down in the bed. The line of pull beneath the upper tibia is at 90 degrees to the bed instead of 60 degrees; otherwise the considerations are the same, with double pulley at the foot and the lower leg supported on a pillow. When the patient is ready for surgery, either in a matter of hours or a week, surgical fixation is planned.

Anesthesia

Any general anesthetic employed at the hospital where the procedure is being done is suitable. The major consideration should be the anesthetist's familiarity with the agent used. We prefer drop ether but frequently use pentothal reinforced with nitrous oxide. Spinal anesthetic is the first choice with many excellent surgeons, though we dislike it. The virtues of local anesthesia have been overemphasized, though it can be used successfully in special instances. When it is the agent used, the hematoma which lies within the joint capsule is injected with 2 per cent novocain, and the subcutaneous tissues overlying the line of incision are infiltrated with 0.5 to 1 per cent novocain. Local anesthesia, in our opinion, is contraindicated when competent anesthetic help is available, for a patient in poor condition can stand a short anesthetic, if properly administered, of ether or pentothal nitrous oxide. The mental trauma and the physical discomfort of lying on a hard table in one position as well as the frequent twisting, turning, and struggling under local anesthesia, tend to prolong the procedure, and on occasion will be directly responsible for a poor result even when initial satisfactory reduction has been secured, for patients tend to shift about during the nailing procedure and lose their reduction. The patient's discomfort leads the surgeon to attempt short cuts to the important steps of a successful routine in an effort to get the patient off the table and back to bed more rapidly.

The premedication will depend on the choice of anesthetic agent and the age and condition of the patient. In adduction fractures it is well to have the patient's blood typed and cross-matched, for, if the procedure is prolonged, blood is the most suitable fluid to maintain pressure, prevent shock, and give an additional boost toward rapid ambulation. However, the average hip nailing does not require a transfusion.

Technic of Reduction

In our practice we use the Bell table though, of course, there are many other suitable fracture tables. The work can be done on a regular operating table with an assistant to hold the foot after reduction. The Bell table (Fig. 2) is arranged with a sheet folded from corner to corner so that it may be tied on itself after passing beneath the patient, between his legs and to the opposite corner post at

overlap of the proximal or head fragment (Fig. 3) as though it were caught inside of the projecting inferior lip of the neck fragment. In other words, the neck lies beneath the proximal fragment ever so slightly so that the proximal fragment cannot displace inferiorly (McElvenny). In this way the neck supports the head much as a McMurray osteotomy supports the proximal fragment after medial displacement of the shaft. If this most desirable position is not obtained, at least there must be no over-riding of the neck on the head. The head should

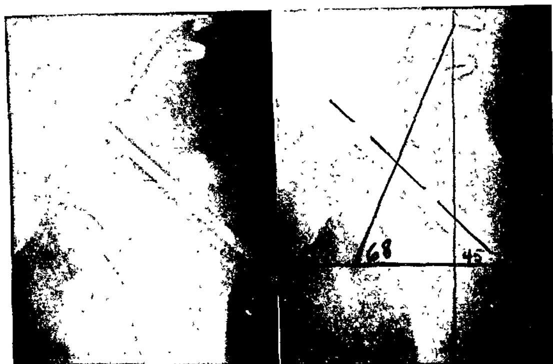


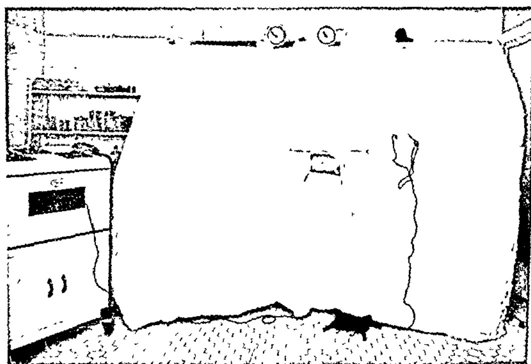
Fig. 3.—A steep angle fracture well reduced so that it is properly caught with the proximal fragment locked inside the distal fragment. The angles represent Linton's angle (see Fig. 4) and the angle of nailing. The angle of nailing parallels the inferior neck margin and the nail is driven to the proper depth. It could be completely against the cartilage margin of the head, but in its present position gives an excellent hold. The screw pin locks the reduction so that it will not be shifted by unsatisfactory nailing attempts. It also acts as a guide to proper nail angle and length.

lie in valgus, however slight, to avoid shearing stress and provide an impacting force. No trace of varus is to be accepted under any circumstance. In the lateral position the neck should be perfectly aligned with no rotation factor. Actually from a practical standpoint 5 to 10 degrees of external rotation can be tolerated with good results. Once a suitable reduction has been obtained, as seen by roentgen visualization, the fragments are nailed. We consider the Smith-Petersen nail the most useful nailing device, though we are well aware that there are many other fixation devices.

Operative Technic

The upper femoral shaft is approached through a lateral incision from the tip of the trochanter 6 inches distally, paralleling the lateral intramuscular septum.

A



B

Fig. 2.—(A) Bell table with both x-ray machines properly placed; a sheet is passed under the patient and between the legs which are fixed to the Bell table upright, the fracture is reduced and in position with the opposite hip flexed and the leg suspended. (B) A long single drape sheet covers all but the operative field.

to back out. It will not force its way through the cortical cancellous subchondral bone beneath the cartilage of the head unless this surface has been penetrated by the original nailing. This layer of bone between the nail and the hip joint is hard enough so that the nail backs out rather than works its way through into the joint. However, if too long a nail is driven through the articular cartilage of the femoral head and changed to a shorter nail of the correct length, the nail may penetrate. One should, therefore, renail in a different direction if the original nail penetrates, rather than replacing the long nail with a short nail in the same channel. If for some reason the original tract is desirable, one should be prepared to change nails at a secondary procedure later. A nail will seldom back out if nailed deeply enough to get a firm grip in the compact cancellous bone of the head. Of course, if several attempts are necessary to gain proper nail position, the head fragment may be broken down so that a firm hold cannot be secured by the nail. If nailed too short, there is also an obviously insufficient grip, allowing the nail to work back out or the head to slip or roll on the nail point. If the external cortex is badly splintered in placing the nail so that it does not act as a fixed guide point but allows rotation of the base of the nail, this motion will be transmitted to the nail point, and the nail will eventually lose its grip and back out. If the lateral femoral cortex should be badly splintered and a plate deemed necessary, the nail should be placed at least 1 to 1.5 cm. short of the articular cartilage in the femoral head so that as settling occurs prior to healing of the fracture site the nail will not penetrate. Here, of course, it cannot back out because of the plate or other fixation device and erodes more deeply, toward or into the hip joint.

Another factor which should not be overlooked in nailing is that the nail acts as a guide on which the head settles into place, and for this reason it must parallel the neck to be ideally placed. This also explains why three pin or other technics, though sometimes successful, are frequent failures. Here the head is toenailed into a fixed position, and, if much necrosis of the neck occurs, the head tends to fall off the neck fragment as the necrosis leaves it with a steadily decreasing bony base. If all fixation devices are parallel in the head so that the head is not held in a fixed position but can slide down the neck, additional screw pins or other screw pin devices work satisfactorily. We like Austin-Moore pins for an occasional fracture, but to be successful this principle must be followed and the pins placed in a parallel manner. If the Smith-Petersen nail is placed across the angle of the neck, there is an increasing tendency for the head to displace, depending on the degree at which the line of nailing crosses the line of the neck.

Occasionally we meet special problems in nailing, as mentioned by De Palma, where hard heads will not accept the nail or where the head is so osteoporotic that it will not offer a point of fixation. These are extremely rare complications; we have never seen the first, but have occasionally encountered the second.

After the nail has been properly placed and checked roentgenographically, the wound is closed and dressings are applied. We prefer a stockinette wrap from the toes upward, wrapping about the upper thigh and waist. This tends to eliminate the dead space beneath the fascial lata which often harbors a hematoma which may become secondarily infected.

After skin drapes are fixed to the wound margins, the fascia lata is incised and the vastus lateralis is either lifted from the bone along the lateral intramuscular septum or split in the usual muscle-splitting maneuver. We prefer blunt splitting to cutting since less bleeding usually results. Before starting the nail, a smooth or threaded Steinmann pin is placed from the trochanter at the gluteal line into the head of the femur. The Steinmann pin is placed on a line paralleling the inferior margin of the neck and running upward and inward at an angle of 45 degrees with the shaft. The lateral position of the Steinmann nail is judged by the roentgen shadow of the neck in a lateral position. Since the film is taken parallel with the floor, any inclination of the neck shown on the film will be either up or down in relation to the operating room floor. This pin is used chiefly to fix the femoral head before driving the nail and thus prevents rotation of the head fragment which might occur if the Smith-Petersen nail should strike at the edge of the head fragment. This precaution was adopted by us after many sad attempts with loss of position and necessary re-reduction. It takes a few moments longer but saves hours in case of surgical accident. After placing the Steinmann nail, we select a point 0.75 to 1.25 inches distal to the gluteal line for the center of the nail. This will usually be opposite the lesser trochanter. It is wise to feel around the femur to be certain of the level before placing the nail. It is difficult at first to estimate the nail's length, but if the nail is started at the level of the lesser trochanter and parallels the neck, an 11 or 11.5 cm. nail for men and a 10 or 10.5 cm. nail for women will, as a rule, be used. This is an over-all measurement. Shorter nails are used in more transverse nailings. One or 1.5 cm. of the nail can be counted on to stand away from the lateral surface of the shaft. There is usually a 20 to 25 per cent magnification roentgenographically owing to the nearness of the x-ray tube. The known length of the screw pin driven into the bone can also be used to estimate nail length.

A small chisel is used to start the nail, cutting slots at 60 degrees from a common center. The nail starter may be used, but it causes more trauma and shock and offers no advantage. The Smith-Petersen nail is driven across the fracture line until it strikes the dense cancellous portion of the head. Before driving it deeper into the cancellous portion of the head, a film is taken to check position. If the nail is improperly placed, it is easily discovered at this point before pulverizing the cancellous central fragment of the head. If necessary, the nail may be redirected, its length again estimated, and the nail driven home before another film is taken. In nailing we strive to have the nail on the anteroposterior plane lie in the center or just below center of the head so that it will not cut out of the top of the head by weight-bearing or shearing thrust. In the lateral plane we strive to have the nail placed just behind center or in the center so that external rotation will not allow it so cut out anteriorly. The nail is placed deep enough so that it lies just beneath the cartilage cap of the femoral head, since the only real hold it has is on the dense cancellous bone of the head. It has no grip on the cortex of the shaft, the cortical entrance point acting only as a directional guide point not as a fixation point for the nail. As the minimal aseptic necrosis of healing occurs at the fracture site with settling of the fracture surface irregularities producing an over-all confluence prior to union, the nail tends

the supposed rate of increase in union, though there is certainly no reason why this procedure should not be followed.

At one time a previous associate of ours, Dr. Bret Smart of Oakland, ran a group of cases at the San Francisco City and County Hospital. These hips were nailed and grafted primarily. The preponderance of grafts done were iliac, though some tibial grafts were used. The nail was properly placed, and then a ⅜ inch drill hole was placed either above or below the nail crossing the fracture line. The graft was shaped to fit and taken from the tibia or from the wing of the ilium with a cork-borer type of graft device designed by Dr. Smart. Careful and critical analysis of these cases was so disappointing that the practice was discontinued. Aseptic necrosis, loss of position, etc., were as common with the nail graft technic as they were with simple nailing. The results were correlated to the type of fracture and in no way influenced as to the rate of healing by the addition of a bone graft.

Pathologic Fractures

Pathologic fracture commonly occurs with metastatic carcinoma. We believe in nailing the fracture since it provides fixation, thus freeing the patient from traction and eliminating pain. This often allows an extended period of ambulation. Roentgen treatment also will occasionally result in late fracture when used for pelvic malignancies. Some authors have reported this condition to be an endarteritis, others a marked increase in local vascularity at the fracture site. Whatever the situation is, nailing is undertaken as above outlined. We have even nailed an unbroken femoral neck in hopes of preventing fracture in a rarefied neck when the opposite side had already been fractured and nailed. So far fracture of this rarefied neck has not occurred, and the fractured side has healed satisfactorily. The ultimate outcome of this case is unknown as yet, for only one year has elapsed since operation. The occurrence of bone rarefaction and the ease of healing seemed to point, in our opinion, to the theorem that this is a matter of local increased vascularity.

Open versus Closed Nailing. There has been a great deal of controversy over the problem of open versus closed or blind nailing of these fractures. In early practice all operators used the open route until Johansen popularized the blind technic. For a time following this the blind technic enjoyed greater popularity, and it is still the most popular method of fixation. However, at present several careful thinkers and excellent men in the field are using the open technic. The incision is either an anterior iliofemoral of the Cubbins type or an anterolateral incision between the gluteus medius and the tensor fascia femoris, extended down the lateral intramuscular septum. We prefer the anterolateral exposure for this purpose since the muscle origins are not disturbed, and we feel that postoperative strength is more rapidly regained. However, exposure is better with the anterior iliofemoral or Cubbins type. In the anterolateral exposure care must be taken not to injure the superior gluteal nerve as it crosses to the tensor fascia femoris. If the interval between the tensor and gluteus is opened bluntly, the nerve will fall unharmed, free on the tensor or medial side of the incision. The exposure is most easily done by first making the usual incision through the fascia lata. The index finger comes from the inferior surface of the gluteus medius

Postoperative Care

We are not in favor of postoperative traction, for we are attempting to impact not distract. If traction is used at all, it must be only enough to relieve muscle spasm, for we have had 2 cases in which the hips were disimpacted by postoperative traction, both hips eventually reaching nonunion and requiring late osteotomy. If the leg has a marked tendency to external rotation, this can be controlled by having the patient wear a shoe with crossarm affixed to hold the foot and leg in internal rotation.

The patient can be up on the first postoperative day, but we see little to be gained in the average instance and usually start our patients sitting on the edge of the bed as soon as the worst of the postoperative soreness and stiffness has passed on the fourth or fifth day. The patient will begin with crutches sometime between the seventh and 10th days, except for an extremely active individual who may get on his feet sooner. The patient is sent home during the second or third week, on crutches, or, if afraid of crutches or awkward in their use, in a four-wheeled invalid walker. We do not insist on crutches, for some patients are unable to learn good balance and co-ordination and occasionally have been known to fall, fracturing the opposite hip.

No weight-bearing is allowed on adduction fractures of the femoral neck for six months and not then if roentgenograms show evidence of aseptic necrosis of the head or if union seems unsatisfactory at this date. Usually from the sixth to ninth month films will show satisfactory early healing, and weight-bearing may be allowed. At first the patient will use both crutches, bearing some weight on the involved hip. Gradually he will discard one crutch and then may use a cane or be completely free of support.

Early in the postoperative course we encourage abduction, flexion, and extension exercises but do not force our patients, feeling that forced motion may occasionally result in loss of position. We assiduously avoid external rotation and adduction. During the first two to three months we become more insistent on good hip motion, and between the fifth and sixth months, if roentgen films are favorable, we like to begin some progressive resistance exercises of the gluteus medius.

It is only fair at this point to reiterate that there are many special nailing technics used by excellent surgeons. Some of these vary but little while others are quite different. One of us prefers a technic using the heavy graduated wire and cannulated nail. With this technic care must be exercised not to kink the wire and thus drive it deeper and not to allow it to catch in the cannulated portion of the nail while driving. It is an excellent technic, and though there are certain advantages, there are also some disadvantages. It makes an excellent alternate technic. There are many other fixation devices such as screws, lag crews, "Z" nails, etc., any of which may be used satisfactorily, provided a detailed routine is worked out by the surgeon and followed meticulously.

We have preferred to outline our technic because we feel it is a quick, simple, and practically foolproof routine.

Much has been written about the advantage of a primary bone graft at the time of nailing. There are many excellent reports in the literature, but we question

pelvis is approximately 5 to 7 degrees, one can be certain that Linton's angle will be only 5 to 7 degrees greater than Pauwels'. It is absolutely essential in measuring these angles that the full view of the femoral neck be represented on the film, and this is done by holding the fracture in internal rotation. For this reason the nailing films are the only ones truly suitable for such measurements. The measurements are taken from the distal fragment and not the proximal fragment (Fig. 4).

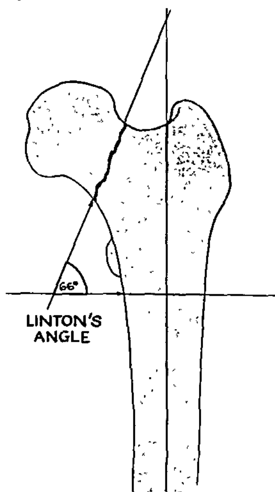


FIG. 4.—Linton's angle, measured on the distal fragment, an angle made by continuing the line of fracture until it crosses a perpendicular to the line of the shaft. This must be measured with the hip in internal rotation.

Since we know that fractures having a high angle, of the adduction type, are likely to result in nonunion, we have elected to treat them with primary osteotomy rather than to wait for a nonunion to develop. Linton found that angles of more than 45 degrees were especially likely to cause difficulty. Previously the objection to osteotomy has been a loss of knee and hip motion owing to postoperative plaster fixation as well as an exaggeration of knee valgus. However, with a high McMurray osteotomy the loss of length is minimal; and if these osteotomies are treated as intertrochanteric fractures and nailed and plated, they do not result in a loss of either knee or hip motion. We have used

and tensor, being passed superiorly from the trochanter. One easily falls into the grove between muscle bellies, and division in this plane without damage to muscle or nerve is possible. This is much easier than attempting to find the plane externally, from superficial to deep, between the two muscles. After a **T** incision of the capsule leaving a lip of fibrous tissue at the acetabular margin, the fracture site is inspected. Reduction is then performed, and it is only fair to say that it is not always simple. It is amazing how difficult it is to be absolutely certain that reduction has been complete. Once reduced the fracture is fixed with a Steinmann nail as in the blind nailing procedure. The Smith-Petersen nail is driven up to the fracture line before the final reduction is made to be certain that it is well centered and then driven home. Check roentgen films are taken, placing the film in a cassette under the patient, first in the anteroposterior and then in the lateral view. The lateral view is accomplished by abduction and external rotation of the femur without moving the x-ray tube. The procedure can be done either on a fracture table or on a regular operating table. It has been our clinical impression that union has been more frequent and undisturbed using the blind technic for the average fracture, though certainly there is no great difference. The blind technic is easier to use from a technical standpoint and subject usually to less in the way of operative complications. With poor roentgen facilities and a good operating team the open method may be somewhat preferable. But if working conditions are ideal, the blind technic is certainly to be preferred.

We have tried De Palmas's technic of wedge osteotomy of the neck at the time of open operation. Certainly union does not necessarily follow and here, also, it depends on revascularization of the head. Shortening of the neck without transplantation of the trochanter may also result in occasional dislocation of the hip. Certainly if one leans toward open technic, the osteotomy of the neck should be practiced on unstable fractures. It is, however, unnecessary on the more stable types.

Primary Osteotomy

It has long been recognized that some 15 per cent of fractures of the femoral neck do not heal because of poor nailing, loss of position, poor circulation of the head, or some other factor. Lloyd in 1938 made the oft quoted statement that "the bad results of nailing are generally the results of bad nailing." This, of course, is partially true, but it is becoming increasingly apparent that there are many other important considerations in the problem not covered by that quotation. One cannot always be certain whether a fracture will give a good or bad result, but almost always those which are going to give bad results can be picked prior to the complication by certain roentgen characteristics.

Fractures of the femoral neck have been divided by both Pauwels and Linton, according to the shearing angle of the fracture line. We prefer Linton's technic because it utilizes the angle between the fracture line and a perpendicular to the line of the femoral shaft rather than the angle between the fracture line and a base line drawn through the pelvis. The pelvis is seldom included sufficiently on the film to make Pauwels' angle determinable; and since Fick has shown that the angle between the long axis of the femur and the vertical plane of the

osteotomy line healed readily in three or four months. The head fragments settled down on the displaced shaft with resultant healing shown roentgenographically. We have been fortunate in being able to follow this patient so that we know that her range of motion is almost equal to that of her normal side, there being a loss of about 30 degrees in flexion and 10 degrees in extension. Her shortening is 0.75 inch. She had a small increase in her physiologic knee valgus. This treatment was a radical departure in treatment but a theoretically sound deviation from the usual procedure and one which we use routinely now under special circumstances.

At present if a fracture is unstable with an increased shearing angle or if reduction for some reason is not satisfactory to the surgeon, osteotomy is done as a primary procedure. Angles of from 45 degrees upward are considered unstable, though occasionally such a fracture may be reduced so that the proximal fragment is caught by the distal fragment. If reduction seems secure, that is, stable, it may go on to successful conclusion, and in this case osteotomy would not be done.

This group of fractures, as already noted, though they may heal, will also carry a high percentage of aseptically necrotic heads and nonunion so that when a satisfactory method of handling is available, it seems only reasonable to take this course and save the patient an extra procedure.

Two sites of osteotomy may be chosen; either a long oblique sectioning of the femur from 1.5 to 2 inches below the gluteal line upward to come out just beneath the neck of the femur, or an even more oblique line of sectioning which passes along the inferior surface of the femoral neck including it in the distal fragment. The first type is satisfactory except for one feature, that is, the increased knee valgus. This occurs whenever the femoral shaft is displaced medially and becomes greater the further the displacement is accomplished because the suspending arm of the femoral neck is by-passed; thus, the normal knee is displaced into apparent valgus. This physiologic knee valgus is ordinarily not apparent. As the femur is shifted medially under the head with shortening of the neck, the long axis of the femoral shaft becomes more parallel with the mid-sagittal plane. In other words, the effect of medial displacement is similar to abduction at the point of osteotomy. In some persons this is minimal and unimportant; in others, who have some initial valgus, it is important and often results in knee pain due to strain of the medial collateral ligament. It has been severe enough in certain cases to require osteotomy at a lower point (Schumm). The advantage of the higher osteotomy, which might be likened to a low and oblique Leadbetter though it differs in several features, is that less medial displacement of the margin of the shaft under the unstable head is necessary; hence, there is less knee valgus. It is also much easier to get adequate medial displacement of the femoral shaft. In either this technic or the high McMurray, medial displacement of the shaft is essential to uniformly satisfactory results. We realize that in many instances it is the change from a shearing to an impacting angle which is truly important, but there are many instances where the osteotomy must also eventually support the head for a satisfactory result. Because of this we consider the McMurray principle the most useful over-all plan.

In attempting to conquer so difficult a problem, one must adopt the procedure

a simple Schantz osteotomy, merely changing the shearing angle to an impacting angle, as Linton suggested, with success in some fractures. But it is our confirmed belief that the high oblique McMurray type is the most suitable. If union does occur, the Schantz is satisfactory; but if it does not occur, as when a dead head fragment is present, then the McMurray, with medial displacement of the shaft, is more likely to be successful, for its acts not only to change the angle but also as a mechanical support to the head fragment, preventing its downward drop.

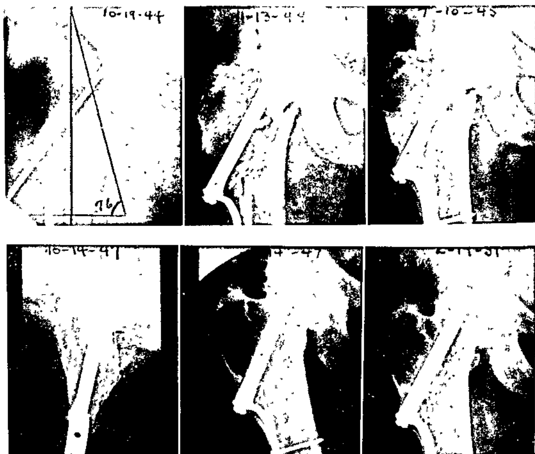


FIG. 5.—A steep angle fracture which slips by easily, being held in reduced position merely by proper traction. Since it was reduced five times and would not lock, primary osteotomy was done. Note that here the osteotomy includes the inferior margin of the neck. Bone chips have been added at the osteotomy site. With this osteotomy the angle is made more sloping and the head fragment is supported by the shaft fragment.

Our first primary osteotomy was done in October, 1944, on a patient whose reduction for a midcervical fracture had been attempted five times. Reduction from the over-reduced to the under-reduced position could be altered by slight changes in tension of the leg-holding device on the Bell table (Fig. 5). It was obvious that reduction would be extremely unstable regardless of the type of fixation used. Because of this a high McMurray osteotomy was decided on, including the inferior margins of the neck. This was executed as a primary procedure. The results were more heartening than we had dared hope. The

may maintain its shape and contour even with nonunion between it and the osteotomy site. Of course, the reason for this gradual dissolution of the head is clear when we consider the pioneer work of Phemister, elaborated in greater detail recently by Phemister and Sherman. It is quite clear that a head undergoing creeping substitution over a period of years from its vascular adhesions may fragment irregularly with irregular replacement, or it may gradually become a soft shell which is easily crushed by some sudden force.

From a mechanical standpoint osteotomy with successful medial displacement of the shaft gives a relatively stable hip, even with nonunion between head and osteotomy. Here there is the effect of a secondary joint, for the weight-bearing is taken on the head by the cupped shaft trochanteric segment. These patients have some limp but can get about with only a cane with no appreciable disability in old age. If they were younger and attempting hard labor, certainly more would complain. With necrotic heads which appear roentgenographically incompatible with comfort, the patient will have a stable and painless hip. These hips will almost never take hard work, but certainly in the presence of the osteotomy with its change from leverage force to more direct impact there is often no complaint. Also there is often some increase in support because of the angle of the osteotomy as the femoral shaft comes to lie against the side of the pelvis. One cannot predict the patient's clinical state from the roentgen film, and, therefore, should refrain from treating the film and concentrate on the clinical complaints. It is most interesting that to date, in spite of the roentgen appearance—and it is sometimes unbelievably bad, we have never been forced on this score to do any other procedure because of necrosis of the head associated with nonunion. Necrotic heads which are healed to the neck may result in much more painful and disabling changes. Motion is also well maintained in all our osteotomies since they are mobilized at an early time and treated exactly like intertrochanteric fractures. Shortening is not over 1 inch, and frequently with a high osteotomy it is less. Weight-bearing is begun as soon as healing of the osteotomy is secure, usually from three to four months. With these technics we have had no nonunions or delayed unions of the osteotomy site since the osteotomy is self-impacting.

Over a period of years an osteotomy with nonunion of the head to the shaft will gradually lose its angle (Fig. 6), or it may wear off its projecting ledge; but usually, if this complication supervenes, there is sufficient dense fibrous tissue to give a firm union and the hip does not become more unstable. Of course, with union of the trochanter, head, and shaft, the above forces are not at play on the osteotomy site, and there is no consequent change. One should also bear in mind that the fate of the head cannot be ascertained in a year but must be evaluated over a period of from two to five years. In the majority of our cases the fragments of the head look good throughout the first year, but a large percentage shows progressive fragmentation after this time. The important finding in spite of this advanced aseptic necrosis is that these patients have almost no clinical complaint.

Treatment of Nonunion

It is apparent from the many technics evolved to care for the problem of nonunion with living or dead head and normal or disappearing neck, upward dis-

which will best answer whatever complications may arise. The osteotomy through the inferior neck is our favorite at present, though the high McMurray is a close second. It is accomplished by nailing the fracture after reasonable reduction. The osteotomy is outlined by drill holes below the nail and along the anterior surface of the shaft below the course of the nail. A wide osteotome is then driven through the course marked out by the drill holes to include the shelf of the inferior margin of the neck up to the fracture line. Prior to this, or at this moment, the inferior neck is cleared to the inferior acetabulum. The severed shaft and neck fragment are then abducted, medially displaced, and adducted to neutral, then shortened to lie in close approximation beneath the head fragment. The shaft is then fixed in proper relationship, using a Thornton four hole bar, bent in the region of the first screw hole, increasing the angle of the plate to about 30 degrees. If the bar is not bent, the plate will displace the shaft laterally to normal position as it is tightened. If the plate is bent at the attachment for the nail, it frequently cracks since this is a weak place in the bar. Furthermore, if the plate or bar is bent too high so that the plate does not come to bear on a part of the greater trochanteric fragment beneath the nail, the entire assembly may shorten with the trochanter, splintering and allowing penetration of the nail into the acetabulum. After proper positioning any gap between the head fragment and the shaft, can be filled with chips from the anterior upper femoral surface or with iliac strips. It is unnecessary to cut a wedge since in pulling the trochanter distally with the nail inserted to attach it to the femoral shaft and at the same time maintaining medial displacement, there will be some telescoping of the trochanter on the shaft, the amount determined entirely by the bend of the plate. It is essential that after sectioning the femur the shaft be externally rotated approximately 10 degrees since the upper or trochanteric fragment normally falls in this position. Unless this precaution is taken, the patient will have a permanent internal rotation deformity. This is much more disabling than many times the same amount of external rotation, for the patient keeps tripping over his own toes. One must be careful in this type of osteotomy with an old fracture, which displays shortening of the neck and has a resultant relaxed capsule, that abduction is not overdone. If such shortening is present, the above plan will often result in dislocation of the head from the acetabulum. In these cases either a low McMurray's or some other reconstructive procedure is more desirable. The fixation of the head to the trochanter without a neck, plus the marked abduction of the shaft, acting as a powerful lever arm on returning to its neutral position in the presence of a relaxed hip capsule, is frequently followed by dislocation. Osteotomy has generally been done as a blind procedure, but in certain instances we have used it as an open technic, employing the anterolateral full hip exposure.

In following these cases we have noticed that when the head heals in at the osteotomy site and its circulation is intact or when it is revascularized rapidly, the contour of the head is not disturbed by changes of aseptic necrosis. However, when circulation of the head is not restored, the head stays as a dense, unchanged fragment, slowly absorbing at the point of contact with the neck, or with nonunion often gradually disintegrating and collapsing over a period of several years until it is hopelessly misshapen, as seen in the roentgenogram. The head, if viable,

placement of the shaft, etc., that osteotomy is not always the choice, especially late in the course of this condition when changes have become advanced. It is true that osteotomy can usually be considered, but many times there are other excellent technics, all having their special advantages. These divide themselves most easily into two main groups, depending on the viability of the head:

(1) Nonunion with a living head
  (a) neck well preserved
  (b) neck absorbed
(2) Nonunion with a dead head showing necrosis

The following group of procedures is a good working outline, though it does not encompass all suggested forms of therapy. In our opinion one of the following technics will care for any nonunion problem if properly selected. We consider them the most certain of success.

In the presence of a living head with a well preserved neck the choices open to the surgeon are:

(1) Osteotomy
(2) Brackett reconstruction
(3) Nail and graft

If the neck is resorbed, the following choices are suitable, depending on the degree of absorption and viability of the head:

(1) Osteotomy
(2) Brackett reconstruction
(3) Luck reconstruction
(4) Moore's cartilage cup arthroplasty
(5) Replacement with prosthesis

If the neck shows marked resorption with a nonviable head, the surgeon must decide on one of the following:

(1) Colonna reconstruction
(2) Moore's cartilage cup arthroplasty
(3) Vitallium mold arthroplasty of the Whitman, trochanteric, or intertrochanteric type
(4) Arthrodesis
(5) Replacement with prosthesis

These procedures will be briefly discussed in the following paragraphs.

Arthrodesis. A. B. Gill has been the chief proponent of arthrodesis following fracture of the femoral neck. He chooses especially those cases with rapid early loss of neck length or late cases with marked loss of neck length, gross necrosis of the femoral head, and marked changes of chronic arthritis. He feels that with the above criteria in mind he will save the patient time and a painful hip. He also assures stability which is important, especially when the patient is young and active.

We have tried this technic several times after dislocation of the femoral head when the neck was too short for successful osteotomy, or when the neck was





Fig. 6.—An apparently satisfactory reduction by our early criteria. Here the head fragment is not caught and supported by the short fragment. The nail was left too deep. It should have been renailed. The high oblique McMurray osteotomy with medially displaced shaft could catch the head if it were to slip inferiorly. Note the gradual changes in the osteotomy over the period of three and one-half years.

the time elapse is not great, either a late nailing or a nailing with addition of a graft is acceptable; but there are usually more certain and reliable forms of treatment.

Osteotomy. Osteotomy has been considered at some length in the foregoing. We are especially partial to this technic and use it rather than other procedures whenever we have sufficient remaining femoral neck. Dickson has described an osteotomy which is logical and should yield excellent results. We have had no experience with it, performing the McMurray type, but feel that if one has the right tools to make the correct angles the results will probably be satisfactory. This procedure is preferable with a viable head but may be useful even with a nonviable proximal fragment.

Brackett Reconstruction. After exposure of the hip through an anterior iliofemoral incision, the proximal or head fragment is scooped out to form a socket which receives the distal fragment. The shaft fragment is prepared by rounding off the stump of the neck near the shaft so that it consists of a rounded cancellous surface. The greater trochanter is cut free with the attached gluteus medius and minimus and transplanted down the shaft as far as possible, being reattached with screw or wire. We prefer to hold the reduction with a Smith-Petersen nail, though Austin-Moore pins are quite suitable. The position at the time of nailing is such that the head will not fall off easily since it lies in some valgus. Postoperatively a double hip spica is used which is left in place for six weeks, though weight-bearing is not allowed for several months, depending on the degree of union demonstrated roentgenographically.

Luck Reconstruction. This procedure is essentially the same as Brackett's reconstruction, except that here no attempt is made to use the stump of the neck. The femur is transected at the base of the neck and the upper portion of the neck discarded. The freshened surface of the head fragment is then approximated to the shaft fragment. Position can be maintained with a Smith-Petersen nail (Fig. 7), Austin-Moore pins, or a Steinmann nail, depending on the circumstance. The trochanteric fragment is transplanted inferiorly as far down the shaft as possible. Postoperatively a double hip spica is applied for six to eight weeks, and then motion is started; but weight-bearing is deferred usually for a period of six months. The final decision is made on the basis of roentgenographic evidence of union.

Moore's Cartilage Cup Arthroplasty. Moore's cartilage cup arthroplasty deserves mention because it is ingenious and applicable under certain conditions. With either a viable or nonviable head and poor neck length, the bone of the head fragment can be scooped out until the light can be seen through the cartilage of the head throughout its surface. This cartilage hemisphere is then placed over the rounded trochanter or neck, and the hip is placed in abduction, using well leg boots or a spica for eight weeks' retention and then starting motion. The hips must be held between 60 and 80 degrees of abduction to be certain to maintain the position between shaft fragment and cartilage cup. The trochanter with attached gluteus medius and minimus is transplanted distally on the femur. Moore uses a double hip spica to the normal knee and operated ankle. At six weeks the good hip is free, and at eight weeks the operated hip is placed in balanced traction; weight-bearing is permitted at 10 weeks. The average case

practically nonexistent. Through Ollier's incision the greater trochanter is cleaned of fibrous tissue and placed in the denuded, deepened acetabulum. In some cases the greater trochanter and upper portion of the shaft are used as a free graft, fixing the trochanter into a cleft just above the acetabular rim. The graft falls into contact with the femur, helping by an extra-articular fusion in conjunction with intra-articular arthrodesis.

Gill reports union in 6 of 10 such cases. Our rate is much poorer being 1 of 4. One of our most promising arthrodeses, done according to the Gill technic, is a splendid arthroplasty with from 30 to 40 degrees of flexion obtained, with no pain and clinical stability, though with some shortening; a good result but no fusion.

The reasons for such nonunions are not difficult to ascertain, but we will not discuss them here.

We feel that in certain instances where stability is desirable arthrodesis is a valuable therapeutic aid, but that, in general, some type of reconstruction procedure in which motion is maintained is preferable.

Colonna Reconstruction. Colonna has written convincingly and in detail regarding his technic where the head is discarded and the greater trochanter placed in the acetabulum. He chooses those cases with necrotic heads and loss of neck. After suitable exposure the gluteus medius and minimus are freed from the trochanter to be transplanted down the shaft under light tension with the shaft in full extension and 25 degrees of abduction. The trochanter with its fibrous covering is displaced into the acetabulum. Colonna feels that additional deepening of the acetabulum is not only unnecessary but unwise. A long plaster spica with the hip extended and in 25 degrees of abduction is applied postoperatively, being left in place four weeks. Early motion is then started with a posterior mold and hip suspension. The leg is, however, not permitted to come further toward adduction than 10 degrees of abduction for seven weeks, at which time the patient is allowed up in a walker, progressing to crutches and then full-weight-bearing as soon as possible.

Perhaps in other hands results are more satisfactory. We have had a limited experience with this procedure, but the comment of Speed and Smith, that the procedure too often results in a weak unstable painful hip, seems true. Spontaneous dislocation has not occurred in our cases, perhaps because we have done too few, but these authors remark on this particular complication. Certainly ours have been unstable and painful. The technic, however, is of great value as a basic consideration and is an important contribution to these problems. We feel that if it were done with attention to deepening and widening of the acetabulum with resection of the inferior margin of the acetabulum that it would result in a more stable and less painful hip. This basic technic has been utilized in several subsequent cup procedures.

Bone Graft. In general, we do not feel that freshening of the surfaces of the nonunion and renailing with the use of a nail and bone graft of tibia, fibula, or ilium is a reliable procedure. We realize that the procedure is in wide use, but the same factors which were responsible for the original nonunion remain active. For this reason we prefer some other reconstructive procedure, namely the Brackett or Luck. If the femoral neck fracture was missed or untreated and

be osteotomized since it serves to keep the shaft displaced laterally. No special care of the lesser trochanter is necessary for with fibrous reattachment function is restored. As pointed out by Philip Wilson, though union of the greater trochanter is desirable, no great disability follows a firm fibrous union of this transplant. A cup is inserted which allows free motion of the neck within the cup and motion of the cup within the acetabulum. After closure, well leg plaster boots, preferably long leg on the operated side and short leg on the normal side, are applied with the leg held in 35 degrees of abduction by a crossbar. These are left in place for six weeks and then the hip is mobilized by overhead hip suspension. Care is taken not to adduct for the first two or three weeks of mobilization. A roentgenographic check of position in neutral and abduction may be comforting. Walking is graduated from walker to crutches and then with no support. If no neck remains, the same technic is carried out, displacing the trochanteric stump into the acetabulum, first covering it with a cup of adequate size. In our experience it has been unnecessary to widen the acetabulum, though we make a great point of deepening it and freeing both the inferior acetabulum and the shaft of any tissue or structures which may tend to cause lateral displacement of the shaft. Before the trochanteric area can be displaced into the acetabulum, the external rotators of the hip must also be removed. The important considerations in our opinion are deepening of the acetabulum medially and superiorly, excision of all impediments in the region of the inferior acetabulum, section of the lesser trochanter, displacement inferiorly of the greater trochanter, and fixation in abduction until the trochanter is healed; the hip is held in part by fibrous scar. Of course, by transplanting the glutei with the trochanter a slight loss in height occurs, but this is functionally unimportant.

Colonna pointed out that the trochanter is only 0.75 inch below the tip of the head in the average patient. The usual loss of an inch is really inconsequential and can be easily compensated for. These patients usually have a positive Trendelenburg, but unless great strength and stability are essential the result is satisfactory. In our experience this last technic of trochanteric vitallium cup arthroplasty is the most useful. Of late we have tried primary trochanteric molds and the primary Whitman type of arthroplasties, using the cup as described above. Admittedly we are not prepared to advise this procedure for wide use. However, in special circumstances, such as work with low grades of feeblemindedness and the psychotic, there is a distinct advantage. If the feebleminded are not allowed to walk soon after injury, they forget how to walk and frequently develop severe contractures. It may then be impossible to correct these contractures and to re-educate them in walking. They are also unable to co-operate in the use of crutches or other nonweight-bearing technics, since they forget to remain off the operated leg or are mentally unable to master crutches. Under these circumstances any osteotomy or reconstruction is doomed to failure and a plan allowing early weight-bearing is essential. By either trochanteric cup or Whitman cup procedures four to six weeks of abduction in well leg boots are sufficient, and these patients then can become ambulatory. Many, of course, do not feel pain as readily as other patients and with a relatively stable hip get around remarkably well.

We wish to repeat that this technic should not be done as a primary procedure

at the end of six months is stated to have 180 degrees of extension and 80 degrees of flexion, 5 to 10 degrees of adduction, and 30 degrees of abduction.

We feel that this should be an excellent technic, though our own experience is limited at present to only one case. This single case proves nothing, but it has good results to date.

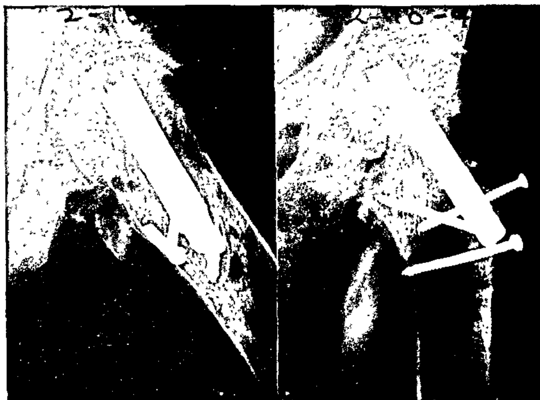


FIG. 7—Luck osteotomy with the head nailed in place and the transplanted trochanter fixed with screws.

Vitallium Cup or Mold Procedures. Vitallium cup procedures are extremely valuable in our opinion, and in the presence of nonviable necrotic head fragments or disappearing necks are easily adaptable. Often union will occur with gradual loss of the dead head as revascularization proceeds, or an area of aseptic necrosis will develop along the weight-bearing surface with symptoms common to chronic arthritis. Here trimming of the head to remove the area of necrosis followed by a formal arthroplasty will improve function and decrease pain (Smith-Petersen et al.). The decrease in pain is the most important result, though in advanced cases where there has been restriction of motion, the motion will be somewhat improved. When nonunion exists with a dead head, the neck is rounded, the greater trochanter freed with gluteus medius and minimus attached so that it can be transplanted inferiorly. The head fragment is discarded; the acetabulum is deepened to and sometimes through the medial cortical plate of the pelvis as well as superiorly. The inferior margin of the acetabulum is resected and all capsular tissue incised so that the shaft can easily fall medially and will not be held away by bone, cartilage, or fibrous tissue. The lesser trochanter must usually

vessels in a frail capsular reflection, and insufficient scope of the ligamentum teres artery which so often result in aseptic necrosis. It has been pointed out that if the head lives even with nonunion present there is usually slight if any arthritic change, and reconstructive efforts are frequently successful. The most severe arthritic changes accompany union of a dead head and its late necrotic changes. Though some changes will occur with nonunion and necrosis of the head, these will usually not show severe clinical disability.

Floyd and George reviewed 300 acute fractures in which 33.6 per cent showed aseptic necrosis. Of course, not all of these patients had severe changes, nor did all of them have complaints referable to the necrotic changes. It is interesting that Linton reported 39 per cent of aseptic necrosis in his series of adduction fractures with a 9 per cent necrosis in the abduction fractures which he reviewed.

Other Complications

Penetration of the nail without osteotomy has been dealt with above. In cases of osteotomy with penetration it is usually feasible to wait three or four months for union of the osteotomy and then to remove all the metallic fixation, for at this time the position will maintain itself. Penetration of the nail seldom results in any severe late changes even with minor excavation of the acetabulum. In some instances nail penetration becomes extreme, and occasionally a nail will work its way into the pelvis. Cases of penetration of the bladder have been reported, and we have one instance of penetration injuring the external iliac artery with formation of a large aneurysm. The aneurysm was treated by a vascular consultant, and the patient retained her leg and its function. This case will be reported later by one of us in collaboration with the vascular consultant.

Nails seldom break, but if they do, the open technic in removing the broken pieces and a reconstructive procedure are in order. By open visualization the nail fragments are easily found and extracted. Following removal of the fragments, the reconstruction plan best suited for the circumstances is chosen, the decision being based on the individual requirements of that particular situation, as previously set forth.

Infection. Postoperative infection is a serious complication in treatment of femoral neck fractures. We have one case of simple abduction fracture that has been on our wards for two years following a simple nailing. Infection became noticeable after penicillin was discontinued in the third week, and the area has drained persistently since that time. The treatment afforded was local drainage followed by hip joint resection and finally amputation, this last being resorted to as a lifesaving measure. This patient is now walking on crutches and will soon be discharged, but she represents the absolute extreme short of death which can occur as the result of infection. The usual problem is that of a low grade infection of a hematoma lying beneath the fascia lata. This must be opened widely and drained. Tubes may be inserted using penicillin, polymyxin, or other antibiotics, but, most important, providing surgical drainage. If this is unsuccessful, and it frequently is because infection follows down the nail tract involving the joint space at the fracture line, more radical therapy is indicated. Once the joint is really the seat of infection, it will seldom clear, without resection of the head fragment and of the acetabular cartilage. One should not wait too long

in fracture of the femoral neck except in these special instances, where other technics are doomed at the start or where prolonged recumbency becomes permanent recumbency. These hips are good but certainly a second best from primary nailing with or without osteotomy when proper co-operation can be obtained.

Replacement by Prosthesis. In these technics either the methyl methacrylate prosthesis of Judet and Judet or the J. G. Collison steel prosthesis, applied as suggested by Peterson, may be used. We have had no experience with either. At first glance one would expect a gradual wearing away of the femoral shaft and the trochanteric region to which they attach or lie against. However, the reports of Judet and Collison and of several other excellent surgeons, commenting on their work, would indicate that, though this approach is not without pitfalls, it may be successfully used in many cases of nonunion of the femoral neck. It is certainly, in its present stage, not applicable to all femoral neck problems. It would seem to us that eventually, with improvement of material and design, some such approach to the problem may evolve which is good enough to be used as a primary procedure for bad risk adduction fractures of the femoral neck. We wish to re-emphasize, however, that the time is not yet here.

Aseptic Necrosis

As pointed out by Phemister in 1939 and Phemister and Sherman in 1947, there are certain peculiarities of adduction fractures of the femoral neck which make them different from other fractures. Our immediate interest revolves about the circulatory features involved. Certainly the presence or absence of blood supply to the head is one of the chief basic problems. A well vascularized head will remain alive in the face of nonunion. It will not gradually disintegrate, and its presence makes possible a much better functioning reconstruction. The head apparently has a variable arrangement in its blood supply. Its chief supply comes from the anterior and posterior circumflex vessels. These lie in the capsule reflected onto the neck, especially reflected onto the posterior neck. Many feel that the vascular supply anteriorly is unimportant. If these vessels are not injured, there may be sufficient circulation to preserve the head. Some of the head circulation enters through the ligamentum teres, but this also is variable and may be a significant section of bone or may be no larger in diameter than a pea. Another source of circulation comes from the vessels of the neck themselves. It must be at once obvious that any injury to any one of these groups of vessels which might supply end-arteries without collateral circulation will result in areas of aseptic necrosis which may collapse unless they are small and revascularized before healing of the fracture has occurred or before weight-bearing is allowed. If the ligamentum teres carries a small amount of the total blood supply to the head and if the vessels are interrupted by capsular tearing at the time of division of the haversian channels of the neck by fracture, then certainly the head will be dead. It is true that a dead head may unite at a point of contact with the vascular neck fragment if reduction is satisfactory. Here, however, revascularization is usually incomplete and aseptic necrosis develops. The head often seems to settle progressively into the neck, being slowly engulfed by living bone year after year. It is this system of end-arteries, vulnerable

range of motion; one of these showed some slimming of the neck. The case treated elsewhere healed in varus with necrosis of the head and was treated at the San Francisco Shriners' Hospital by late osteotomy which corrected the position but did not improve the motion.

The midcervical fracture was manipulated in surgery since traction reduction did not seem adequate. Position could not be held in a double hip spica without metal fixation. To prevent loss of position, on the third attempt a Steinmann nail was placed blindly, locking the trochanteric fragment to the head. Healing was secure in seven months, but there was late asymmetry of the head. Motion, however, was complete. Follow-up has been possible over a period of four years for all except one of these cases.

Brief reports of these cases follow:

J. J., male, aged nine (Fig. 8) was injured Feb. 23, 1947, when he fell from a second story roof while sword-fighting. Roentgen films disclosed a cervicotrochanteric fracture of the femoral neck. He was treated in traction with 6 pounds of weight and manipulated on Feb. 25, 1947, being placed in a double hip spica in extension and 30 degrees of abduction. On Mar. 21, 1947, because of some loss of position, it was necessary to wedge the hip into greater abduction which corrected the deformity. He was at this time wedged to the complete limit of his abduction. His cast was removed on June 12, 1947, and he was started on weight-bearing at that time. Our note made on Nov. 26, 1947, states that he had complete union and a complete range of painless motion.

C. MacN., aged five (Fig. 9) fell from a garage roof on Feb. 27, 1947, and was brought to the hospital on Mar. 2, 1947, complaining of left hip pain. Roentgenograms disclosed a cervicotrochanteric fracture of the left femoral neck. The injured extremity was placed in straight Buck's extension with 3.5 pounds of weight. Because of early varus deformity the left hip was brought into marked abduction on Mar. 7, 1947. On June 17, 1947, three and a half months after injury, traction was removed and the patient was allowed to begin mobilization of her joints in bed. On June 30, 1947, she began to walk on crutches. Films at this time showed excellent healing. She used an ischial-bearing brace from Aug. 10, 1948 to Nov. 25, 1949. When last seen, on Nov. 28, 1950, she had a full range of painless hip motion with no loss of leg length. Films taken at this time showed no evidence of aseptic necrosis other than a slight slimming of the neck circumference.

D. W., aged 12 (Fig. 10) on Oct. 28, 1947 fell from a 10 to 12 foot retaining wall while looking for his pocket knife. Roentgenograms disclosed a midneck fracture. Two days later he was manipulated in surgery, and though reduction was not difficult, using the usual Leadbetter technic, it could not be maintained in a spica in abduction and internal rotation. For this reason he was remanipulated, and reduction was maintained by blind placement of a Steinmann nail buried beneath the skin and external fixation in the form of a double hip spica. On Mar. 5, 1947, the pin was removed but the spica was retained until May 5, 1948. He was carried on progressively increasing weight-bearing, using crutches until Dec. 13, 1949. Since that time his activity has been unrestricted. When recently seen (Dec. 26, 1950) he had a complete range of hip motion. His shortening was 0.5 inch. Roentgenograms, however, disclosed a somewhat misshapen head, though he did not complain of pain.

M. C., aged 10 (Fig. 11), was first seen by us at the Shriners' Hospital in February, 1947. A year and a half earlier she had fallen from a horse, sustaining a cervicotrochanteric fracture of the femoral neck. She had been treated in traction for two months and then placed in a spica for two months. Her fracture had healed in a varus position. Roentgen films showed also aseptic necrosis of the head. Shortly thereafter a curved osteotomy of the subtrochanteric region was done, correcting the varus angle. The greater trochanter was moved down and fixed in a new location lower on the shaft with a single screw. Her motion before and also after surgery was limited to between 20 and 30 degrees of flexion. All other motion was also markedly limited.

to perform this resection; and if the patient shows signs of joint sepsis with generalized toxic symptoms, weight loss, fever, anemia, and general debility, joint excision may be lifesaving. The skin margins may be sewn over the raw subcutaneous surfaces and muscle, obliterating all but the joint cavity and narrowing the drainage surface. Usually this procedure is enough, but occasionally disarticulation must be necessary to save the patient's life.

Thromboses. Orthopedists as a group at one time disclaimed all but occasional vascular thromboses or emboli. We at one time said that we could count our thromboses on the fingers of one hand. At present we are the first to admit that such complications are frequent, even with attention to early exercise and precautions as to supportive wrapping of the lower legs. Now that we expect the complication and recognize it, we often see it. Our usual plan has been to carry the patient on general supportive measures, using in addition *depoheparin* intramuscularly and dicumarol. The patient is followed closely with prothrombin determinations. We like to carry our patients at a prothrombin concentration of between 20 and 30 per cent.

Bracing

We are occasionally asked about bracing when a nailing is unsatisfactory. Weight-bearing is to be avoided in any event, and a long leg brace dangling from the hip only makes displacement more likely. The only brace which could be of value is one with a pelvic band and thigh cuff with a hip joint lock. Here the weight would come on the iliac crests and would not dangle from the hip joint. This is a poor approach to the problem. If nailing needs this much additional support, osteotomy should be done at once. However, bracing is valuable when a nonunion exists in a case which is inoperable. Here an ischial bearing brace may allow comfort in walking and stability which could not be attained in any other way. It should not be forgotten, for occasionally it is the most rational way out of a difficult situation, and in this present day rush to correct all such problems surgically, one sometimes forgets the simple approach.

Fractures in Children

Any discussion should contain mention of fractures of the femoral neck in childhood. These fractures are uncommon, and no one person is privileged to see more than a few such injuries. We have seen in recent years 3 acute fractures in children and one case of malunion. In addition, we have had a case of aseptic necrosis requiring arthroplasty in a woman 35 years of age who had had such a fracture in early childhood.

Of the 4 cases there were 3 cervicotrochanteric fractures and one midcervical fracture. The ages of these children ranged from five to 12 years, and all fractures resulted from severe trauma; 2 fell from a roof, 1 from a 12 foot wall, and 1 from a horse.

The 3 cervicotrochanteric fractures were treated with traction in abduction, 1 until recovery was complete and weight-bearing possible, and 2 with a combination of early traction followed by plaster spica fixation in wide abduction. Two of the cervicotrochanteric fractures healed in four months and had a full

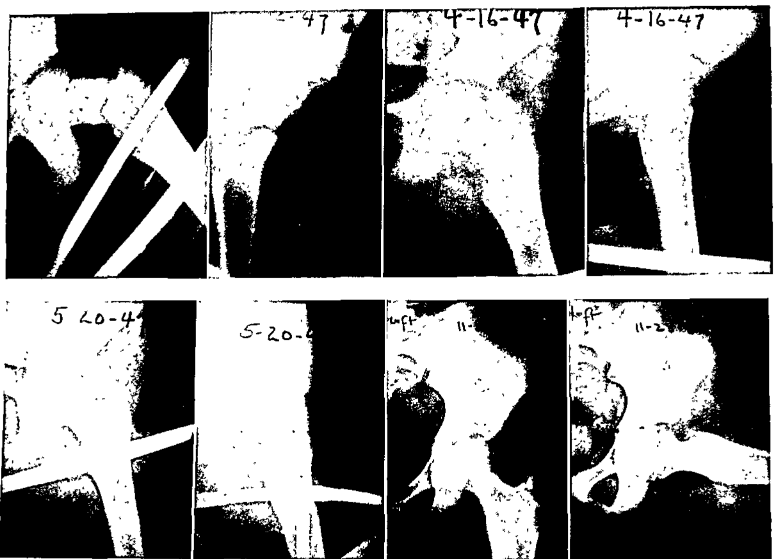
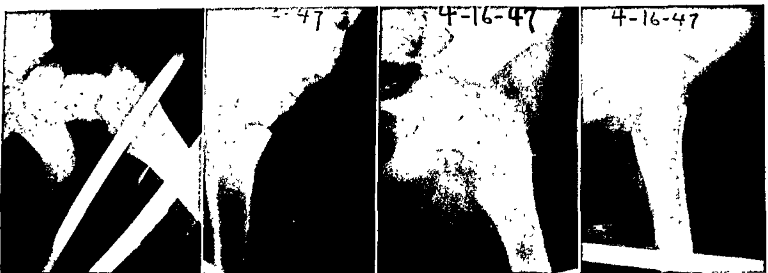


FIG. 9.–C. MacN.: Cervicotrochanteric fracture of the femoral neck at five years of age, at the time of fracture, and three and one-half years later. Note the slender neck



Fig. 8.—J. J.: Cervicotrochanteric fracture of the femoral neck at nine years of age, at the time of fracture, and nine months later.



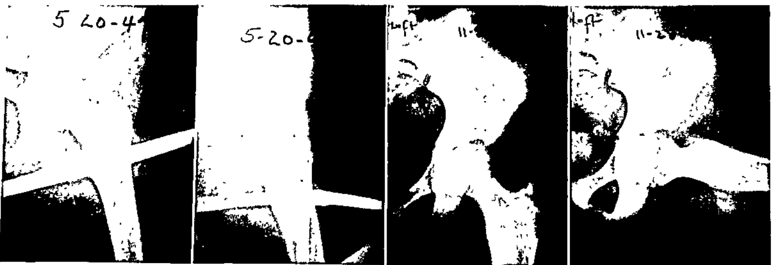


Fig. 9.—C. MacN.: Cervicotrochanteric fracture of the femoral neck at five years of age, at the time of fracture, and three and one-half years later. Note the slender neck without changes in the head.

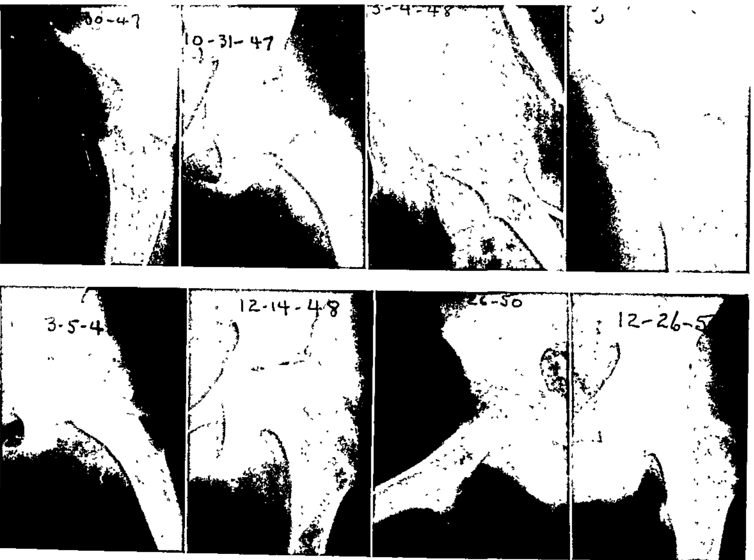


Fig. 10.–D. W.: Mid-cervical fracture of the femoral neck at 12 years of age. Note the changes of aseptic necrosis in the superior quadrant of the femoral head.

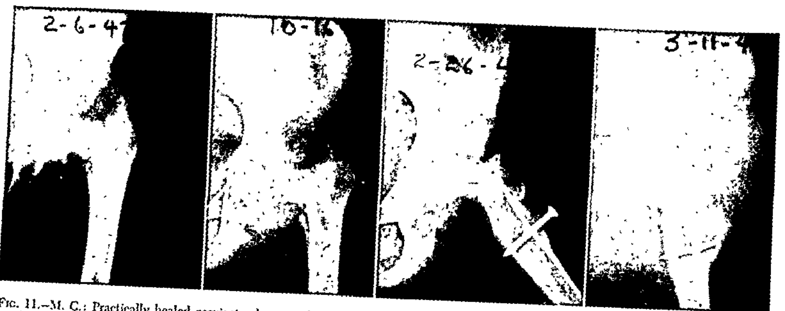


Fig. 11.—M. C.: Practically healed cervicotrochanteric fracture of the femoral neck at the age of 10 years. The fracture is now one and one-half years old. Note the delayed union, varus position, and advanced changes of aseptic necrosis. Correction by late osteotomy.

These cases emphasize several important considerations. Fractures of the femoral neck in childhood do not result from the minimal injury seen with such fractures in adult life. Here the trauma is usually extreme and the child has fallen from a height or suffered other violent injury. The site of femoral neck fracture in childhood is predominantly cervicotrochanteric. Carrell and Carrell placed the incidence at 75 per cent cervicotrochanteric and 25 per cent midneck fractures. The most suitable therapy in these cases is traction in abduction, usually combined with plaster fixation at some stage. Wide abduction is absolutely essential; it is occasionally necessary to section the adductors to get sufficient abduction. One technic used by Carrell and Carrell, Hoke type plaster and wide abduction with traction from the plaster, seems especially applicable, though we used the open traction technic. Traction plus abduction certainly seems the secret of success and metallic fixation is inadvisable unless there is no other way to hold reduction. Some have found reduction in abduction and internal rotation held satisfactorily by a spica in the midcervical type. We found it necessary to add a Steinmann nail to this procedure. We do not feel that such a nail injures the epiphysis, for we have used it often in congenital hip problems with no apparent sequelae. This incidence of aseptic necrosis has been considered higher in fractures in children since it is known that the artery of the ligamentum teres is not patent until adolescence. Though this seems true from our series, the reported incidence of 33 per cent is approximately that seen in the critically analyzed adult cases. Certainly it seems logical that any fracture dividing the haversian circulation, tearing the capsular reflections, and injuring the nutrient vessel with a lack of circulation from the ligamentum teres can only result in aseptic necrosis of the head. It should be remembered. as regards the posterior neck vessels, that the capsule in a child is much heavier in structure, and for this reason the vessels are probably less frequently permanently damaged than in older patients. If union should occur in poor position, it is better to wait until it seems complete, with the local circulation well re-established, before correcting the poor position by late osteotomy at a site which does not interfere with circulation to the neck.

To recapitulate, fractures of the femoral neck in childhood result from violent trauma, and are best treated by traction and abduction in or out of a spica. Healing is usually good at the fracture site, though nonunion is not unknown and poor position is best treated by late osteotomy. The parents should be advised of the likelihood of aseptic necrosis.

In closing we wish to say that though a hip fracture may be the most simple of problems, there still remain approximately 15 per cent of these fractures which will tax the ingenuity and perseverance of the most competent of surgeons. We all owe a debt of gratitude to the pioneers in this field—Whitman, Albee, Leadbetter, Colonna, Wilson—and to Smith-Petersen above all for his great contributions, the nail for primary treatment and the cup for its complications.

Many of these fractures can be handled by one of the above described plans. Selection of the proper technic for the individual problem will require careful thought and meticulous execution if a satisfactory result is to be attained.

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Aseptic (Avascular) Necrosis of the Femoral Head in Adults

WILLIAM COOPER, M.D.

INTRODUCTION

The development of orthopedic surgery in America was perhaps stimulated equally by the need for correction of the severe deformities of childhood and the treatment of serious infections of the bones and joints, especially tuberculosis. With a decline in frequency of tuberculosis, the control of other infections, and the virtual disappearance of rachitic deformities of bone, attention was gradually directed to other areas where the technics which had been developed could be usefully employed. This factor, aided by the discovery of the roentgen ray, was probably the basis for growth of interest in many new orthopedic problems such as aseptic necrosis of the hip in adults, particularly those of nontraumatic origin. Added to this has been the great improvement in treatment of fractures of the femoral neck, which has revealed aseptic necrosis as perhaps the most frequent and formidable of the complications to be dealt with.

Because of this attention, the condition has emerged from obscurity in the past 15 years to become an entity of real importance. Its occurrence as an expression of medical disorders, as well as traumatic causes, is acknowledged, and a vast amount of study has already been directed to its causation and pathology, as well as its treatment.

Aseptic necrosis is a basic pathologic change in the constitution of the femoral head which may have its origin in widely separated causes. The etiologies range from violent traumas to influences so subtle that they often cannot be identified at all. They include metabolic diseases and changes in the atmospheric pressure, and provide impressive evidence of the vulnerability of the femoral head. It seems astounding that from such varied origins, the sequence of pathologic events which follow may be remarkably similar and the final structural alteration almost identical. This final uniformity has in a sense been fortunate in that it has permitted the development of more or less standard methods of treatment.

CIRCULATION OF THE FEMORAL HEAD

The basic defect in aseptic necrosis of the hip, irrespective of the cause, is a loss in the vascularity of the femoral head. It seems obvious that somehow the nature of the blood supply in this area must be directly related to its frequency as a site of necrosis. For this reason, it has commonly been a subject for investigation and controversy. Certain anatomic observations about which there is now general agreement might be set down (Fig. 1):

(1) The principal source of blood supply is via the *medial femoral circumflex artery* which on the posterior aspect of the femoral neck gives off *inferior* and *superior cervical* branches, of which the latter are the larger. These vessels penetrate the capsule at the base of the neck. Some branches enter the neck through foramina at that point, while others run on the surface of the neck in retinacula to reach foramina at the articular margin.

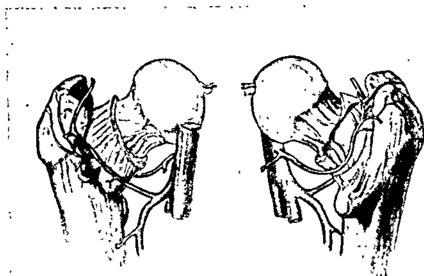


Fig. 1.—Circulation of the femoral head. The figure on the right is a posterior view, showing the inferior and superior cervical branches of the medial femoral circumflex artery, while the figure on the left shows the lateral femoral circumflex artery with its usually small anterior cervical branch. The vessel in the ligamentum teres is generally small and relatively unimportant.

(2) The *lateral femoral circumflex artery* provides a smaller and less constant *anterior cervical* branch which, like the posterior cervical vessels, penetrates the capsule at its attachment with branches entering the bone and others extending along the neck of the head.

(3) The *foveal arteries* in the ligamentum teres can be demonstrated in a large percentage of cases. They are relatively larger in adults than in children but are generally not considered sufficient in themselves to maintain the viability of more than a small apical portion of the head at most.

(4) The *nutrient artery* in the femoral shaft rarely in adults extends even into the trochanteric region.

The controversy which has revolved about the relative importance of these vessels, particularly the artery in the ligamentum teres, makes it probable that variations do exist. It seems more likely that greater variation exists in the influences to which they are exposed. The preponderance of evidence certainly points

to the posterior cervical vessels as the primary source of blood supply, while the others are secondary in importance. These posterior cervical vessels extend a considerable distance by way of the reflected capsule to reach the head, and may be exposed to direct injury from displacements of the upper end of the femur in fractures or dislocations, (Figs. 2 and 3). This, together with the absence of any reliable vascular anastomosis, makes these vessels a long lifeline supporting the viability of the head.



Fig. 2A.—Fracture of the femoral neck three months after injury, with increased density of the head fragment which is presumably necrotic.

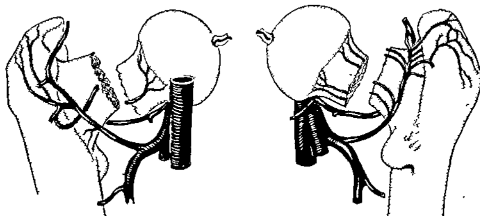


Fig. 2B.—Anterior (left) and posterior (right) views on the femoral neck, showing the probable mechanism of interruption of the circulation.

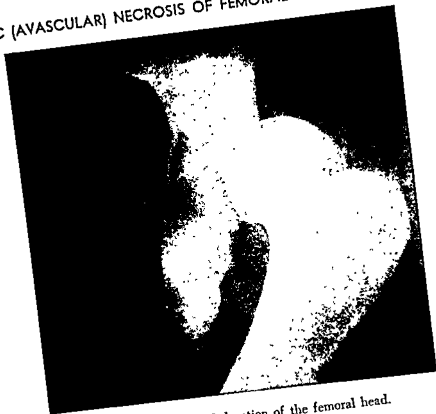


FIG. 3A.—Posterior dislocation of the femoral head.

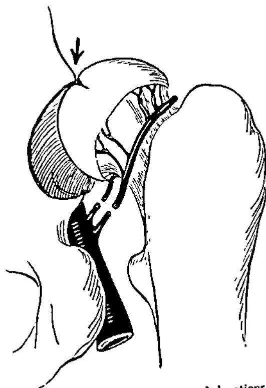


FIG. 3B.—Presumptive mechanism of vascular damage in dislocations, showing also the possibility of damage to the articular surface.

ETIOLOGY

The underlying factor common to all instances of aseptic necrosis is an interference with this blood supply. In fractures and dislocations of the upper end of the femur, the basis for the interruption may be evident, but in cases without such obvious trauma it may be obscure. In children, the growing capital epiphysis is known to be liable to influences which produce the necrotic changes of Perthes' disease, but the adult femoral head is generally considered immune to such influences. Actually no such immunity seems to exist, and the material on which this report is based includes 64 cases of aspetic necrosis from causes other than fracture of the femoral neck, 16 of them bilateral. These were encountered in a single hospital (Hospital for Special Surgery, New York City) over approximately a 10 year period. The number occurring as a complication of fracture was nevertheless even greater. A review of some of the factors which were productive of aseptic necrosis among this group of cases merits discussion.

Fracture of the Femoral Neck

Fracture at this site provides an obvious mechanism by which the cervical vessels, both anterior and posterior, might be interrupted (Fig. 2). The form of the arterial supply coming to the head via the long reflected capsule of the joint and running either in the neck or directly on its surface makes it distinctly subject to damage. The fate of these vessels after fracture would seem to depend on the degree of displacement which had occurred. Vertical fractures from adduction injuries allow greater displacement and greater likelihood of damage. Horizontal or impacted fractures from abduction injuries with lesser degrees of displacement are less prone to aseptic necrosis. Phemister has indicated that the necrosis is generally determined at the time of injury and the head will either inevitably die or not. Compere, on the other hand, suggests that accuracy of reduction and fixation is important in preserving the blood supply. He feels that a partially damaged circulation may be rendered completely insufficient by poor mechanical fixation plus the minimal traumas of early weight-bearing. Experimental studies with dogs are offered by him in evidence. These observations suggest that there may be two distinct processes, one due to abrupt complete interruption of circulation with rapidly developing necrosis, and the other a more gradually developing process of necrosis, dependent perhaps on the management of the fracture. This seems to be borne out clinically. Some cases, such as that shown in Fig. 2A, had advanced changes three months after fracture, while others (Fig. 6A) progressed to excellent union and function without evidence of necrosis, only to develop increase in density and collapse one and one-half years later. The incidence of aseptic necrosis following fracture of the femoral neck has been variously estimated from 15 per cent (Watson-Jones) and lower, to 33.6 per cent (Boyd) and more, in hips treated by internal fixation.

Dislocations of the Femoral Head

As in fractures of the neck of the femur, this type of injury likewise supplies an easily understood mechanism for interruption of the blood supply (Fig. 3). Since the posterior cervical vessels are considered to be of greatest importance

in maintaining the circulation of the head, posterior dislocation would seem most likely to affect its viability. This seems to be confirmed by Urist's reports in 42 cases of dislocation and fracture-dislocation. In this group aseptic necrosis developed only in the 2 cases which had been shown at operation to have gross hemorrhage posteriorly in the retinacula and capsule. Urist believes that if necrotic changes occur they should be evident within six to 18 months, and states that they have not been reported to occur five or more years later. Potts and Obletz, on the other hand, present cases as late as two to five years after fracture, and Armstrong cites the case of a soldier who served as a commando following reduction of a dislocation and only five and one-half years later developed the changes of aseptic necrosis. In Armstrong's series of 101 cases of dislocation and fracture-dislocation, followed two to five years, only 2 showed radiographic changes of aseptic necrosis.

On the basis of the early findings of Urist and of Armstrong, the incidence of aseptic necrosis as a complication of simple dislocations would not seem to be great. On the other hand, Watson-Jones suggests an incidence of 30 per cent in recent cases with a much higher incidence in overlooked cases requiring surgical treatment. It is still not certain whether a follow-up study of cases five to 10 years after injury would not disclose a much higher incidence.

As in the instance of fracture of the femoral neck, it seems that a distinction might be made between those cases in which aseptic necrosis has appeared rapidly following injury (three to six months), and those in which the progression was much slower, requiring several years in its development. It seems possible that there might exist sudden complete interruption of the blood supply as well as some other more gradual process to account for its occurrence either as an early or a late complication.

Caisson Disease

Caisson disease in divers and tunnel workers results from the absorption of increased volumes of nitrogen in the body tissues under the influence of greater atmospheric pressure. With too rapid reduction of this pressure, the nitrogen is released into the tissues in the form of bubbles. In the blood stream it may produce gas emboli which can block small arteries. Tissues with high fat content, like the bone marrow, absorb the largest amount of nitrogen and with its release within the rigid bone structure it can damage by direct pressure on the vessels. Whether either or both of these circulation factors are responsible, the effect is an avascular lesion of varying extent in the bone. The femoral head, with its rather precarious blood supply and weight-bearing stresses, is particularly vulnerable in this process, and may develop extensive areas of necrosis (Figs. 4A and B).

During the recent war the writer examined for retirement 2 air corps officers with bilateral hip disease and roentgenographic findings typical of aseptic necrosis. Both of these men had been test pilots and had done high altitude flying. The likelihood that these lesions in the hips might have been due to atmospheric pressure changes similar to those in caisson disease was considered at the time; the changes presumably having occurred during rapid ascent (Fig. 19E).



FIG. 4A.—Extensive necrotic change and collapse from caisson disease in a 38 year old tunnel worker.



FIG. 4B.—Cross section of the removed femoral head. The bone is extensively necrotic and large areas have been completely replaced by fibrous tissue. The central white and black areas contain no bone at all (see Fig. 9).

GAUCHER'S DISEASE

As a cause of bone pathology Gaucher's disease has only rather lately been described (Pick, 1922). The frequency and nature of the involvement in the hip has even more recently been set down. The disease affects the reticulo-endothelial system into which large amounts of kerasin are deposited. The large, pale reticular cells loaded with kerasin are called Gaucher cells. Involvement of the skeleton is quite characteristic of the disease, and the particular susceptibility of the femoral head, as in caisson disease is prominent.

The onset may be generally in childhood, but in 5 adult cases reviewed for this study, no symptoms were present until after the age of 20 in 3, and in the other 2 the symptoms in childhood had been relatively mild and were ascribed to other causes. It is interesting that in both of these cases it was assumed from the earlier history and the later deformity of the femoral head on the roentgen film, that the patients were presenting the late complications of an old Perthes' disease. Sternal puncture and the discovery of an enlarged spleen corrected the diagnosis in one, and operative exploration established it in the other.

The rapidly proliferating Gaucher cells pack the marrow spaces, surround the bony trabeculae, and resorb the bone, and may infiltrate and occlude the small blood vessels, producing infarction. A picture of extensive bone resorption, necrosis, and collapse may be produced (Figs. 5, A, B, and C).

Other generalized disorders of the reticulo-endothelial system may produce similar destruction of the femoral head but these are less frequent and less clearly defined than Gaucher's disease.

Radiation

Aseptic necrosis from irradiation is relatively common and numerous cases have been reported. In sufficient dosage there may be necrosis of the bone cells and destruction of the blood vessels. The effect of implanted radium is perhaps even more damaging than in radiation with roentgen rays. The gamma and beta rays from even small amounts of radium may produce profound changes in the bone. Such alterations have generally been observed in women who have been treated for pelvic malignancies with radium or roentgen therapy. As in other etiologies, the bone of the weight-bearing portion of the head becomes necrotic and collapses. Fracture through the necrotic bone of the neck is also common in these cases, often bilateral.

In this same etiologic category might be mentioned the effect of radioactive substances taken orally for Hodgkin's and other diseases. It seems unlikely that aseptic necrosis of the hip would result from this cause, but a case has even been cited in which bilateral necrosis followed the use of a nostrum alleged to contain radium.

Sickle Cell Anemia

Aseptic necrosis of the hip, indistinguishable in its roentgen appearance from that caused by other agents, has been produced by sickle cell anemia. The necrosis in this instance is evidently due to capillary stasis of the deformed erythrocytes, with resulting thrombosis and infarction. The nature of the circulation of the hip again produces a tendency to localization in that area.

Idiopathic

Added to this list of more or less clearly defined etiologies is a considerable number of instances in which the cause is unknown. These can be called *idiopathic*. Included in this group are those with a history of trauma but without immediate evidence of fracture. Three cases, which will be discussed later in greater detail, gave a history of direct injury to the hip of sufficient magnitude to require medical attention, but no fracture could be demonstrated. Relief of



Fig. 5A.—Gaucher's disease with aseptic necrosis and collapse of the femoral head.

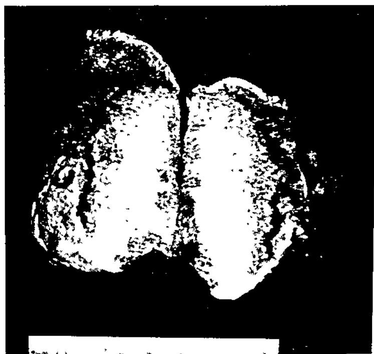


Fig. 5B.—Gross specimen of a femoral head in Gaucher's disease, showing complete collapse of the subchondral bone.

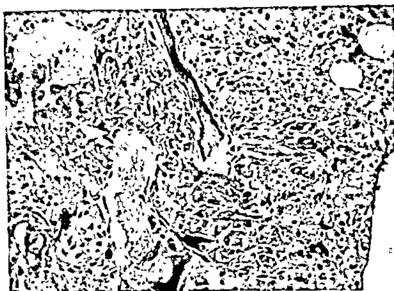


FIG. 5C.—A section of bone packed with Gaucher cells. In this small area there are fragments of dead and regenerating bone as well as the fibrous remains of resorbed bone.

symptoms was quite prompt in all 3, only to be followed in a year or more by progressive aseptic necrosis. It was interesting also, that among this group of idiopathic cases, were 3 ballet dancers and 1 acrobat, which suggests a relationship between occupational trauma and the development of the condition. In 3 of these 4 cases the involvement was bilateral. Leonard T. Peterson, in discussing surgical reconstruction of the hip recently, demonstrated 2 cases of spontaneous aseptic necrosis, one in an acrobat and the other in a parachute jumper. It has been informally stated to the author by a physician to a large circus that collapse of the femoral head is a recognized occupational disorder among circus acrobats. This has not been confirmed, but if correct would provide interesting evidence of the relationship of trauma to this condition. Forced hip movements, overstretching, and jumping might produce a basis for damage to the femoral head and to the circulation. The exaggerated rotation of the hips which ballet dancers regularly practice might somehow obstruct the arteries to the femoral neck.

DIAGNOSIS

From this broad assortment of known etiologies and unknown factors emanate the alterations in morphology by which aseptic necrosis of the hip is recognized. Accurate early diagnosis has been made possible only through the availability of roentgen examination, and the diagnostic criteria for this condition, as for many bone disorders, are, for the most part, in the roentgenographic changes. Of these the most typical are:

(1) Increase in bone density
(2) Structural weakness and collapse
(3) Detachment or separation of bone fragments, resembling osteochondritis dissecans
(4) Osteo-arthritic changes in the hip joint



FIG. 6A.—Aseptic necrosis of the femoral head one and one-half years following union of a basal fracture of the neck.



FIG 6B.—Aseptic necrosis of the femoral head in Gaucher's disease.



FIG. 6C.—Idiopathic aseptic necrosis of the femoral head in a ballet dancer.

But these characteristics are diagnostic only for aseptic necrosis as a whole, and provide little clue to the etiology. The late roentgen changes tend to be so uniform that generally, soon after the onset, it is difficult to find in the roentgenogram any indication of the origin of the condition, except in fractures. Figures 6A, 6B, and 6C, representing aseptic necrosis in Gaucher's disease, healed fracture of the femoral neck, and idiopathic origin in a ballet dancer, respectively, show practically identical changes.

On the face of it, it might seem that these dissimilar etiologies follow invariable courses to similar end-results. However, even a superficial study discloses that the pathologic changes which may occur show great variation. Even in cases with the same etiology, the histologic basis for increase in density, collapse, and the appearance of osteochondritis dissecans is far from consistent.

HISTOLOGIC BASIS FOR THE ROENTGEN CHANGES

It has been pointed out that the basis for an early diagnosis of aseptic necrosis of the hip is primarily a change in the roentgenogram, reinforced in certain instances by a clinical history or other findings which would permit us to establish the cause. The increase in density, collapse, and fragmentation are gross changes obviously resulting from microscopic alterations in the femoral head.

The pathologic sequence of events in aseptic necrosis might be set down simply as follows: The blood supply is interrupted, the bone dies, and the dead bone is replaced by living bone. The mechanism of interruption of the blood supply has been explained in certain instances; in others it was noted as idiopathic or unknown. When the femoral head is deprived of its blood supply and dies, there



FIG. 7A.—A fragment of dead bone with a large mass of lighter new bone being applied to its surface. A row of osteoblasts can be seen along the border of the new bone. Connective tissue surrounds the bone fragment and will resorb the dead bone.



FIG. 7B.—A dense bar of necrotic bone with empty lacunae surrounded by fibrous tissue. Lighter new bone, surrounded by osteoblasts, extends stalk-like from its border on the left, and from its tip on the right.



Fig. 7C.—New bone is being applied to the necrotic bone throughout the section. The dead bone can be identified by its darker stain and empty cellular spaces. The new bone is lighter and surrounded by osteoblasts. The necrotic trabeculum seems to be in fragments which the new bone is attempting to unite.

is a loss of the cellular elements in the bone, and the marrow elements become a formless debris. The articular cartilage may survive in part or in whole, deriving nutrition from the synovial fluid.

The mechanism by which the dead bone is replaced by living bone has been carefully described by Phemister and others and is referred to as "creeping substitution." From living structures adjacent to the dead bone, such as the capsule or neighboring portion of the neck, young connective tissue and capillaries grow into the necrotic marrow spaces and surround the dead trabeculae. A simultaneous process of bone resorption and bone production is rapidly set up about the trabeculae so that while dead bone is being removed by osteoclasts from one surface, living bone may be applied by osteoblasts to another surface. In this way the essential form of the bone may be retained and the dead bone is gradually replaced by living bone. If the process is permitted to proceed undisturbed, complete restoration of a femoral head in its original form might be possible. Figures 7A, B, and C illustrate this process of repair.

The variations of this basic pattern are numerous and many influences may interfere with its regular progress and conclusion. We might consider these in relation to some of the roentgenographic changes.

Increase in Bone Density

On the film increased density is generally the first sign that a femoral head is undergoing necrosis. It has been assumed that this change in the appearance of the bone is only *relative*. When the bone dies it becomes a passive structure and

like a foreign body retains its original density. From disuse, or perhaps from some influence of the necrotic bone, the neighboring bony structures develop osteoporosis and by contrast the dead head appears denser. This femoral is the first basis for increase in density, but other factors probably come into play to accentuate it. In ischemic areas amorphous calcium is likely to be deposited and is occasionally seen in the medullary spaces on microscopic sections. More significant is the influence of "creeping substitution" on the density, after the head has become necrotic. The head may die quite abruptly but, on the other hand, it may possibly die gradually. In either event a new metabolism is promptly set up in which new bone is applied to the dead bone, or perhaps, in the latter instance, to the dying bone. If the bone deposition exceeds the resorption the trabeculae may be remodeled into a much denser framework. Figure 7A illustrates this point. It shows a small fragment of necrotic bone on which has quickly been deposited a large mass of new bone which would obviously increase its density on a film. Areas of the section in Figs. 9-11 show trabeculae which for the same reason are of much greater dimension than normal. The process of resorption and repair is not uniform and the necrotic head may show irregular defects producing a mottled or even fragmented appearance.

Under the influence of weight-bearing the weakened, necrotic trabeculae generally give way and the head collapses, as will be pointed out later. The structural content of the head is then compressed into a smaller volume and becomes obviously and irregularly denser. Defects in the articular surface are often seen on histologic sections and may represent escape valves to permit the easier collapse of the head. Freund and others have pointed out bone dust or detritus in the medullary spaces, postulating that the necrotic trabeculae have been fractured, and then by friction ground into dust. Often, perhaps, it is the pathologist's knife or the technician's microtome which creates the bone dust observed on the slide.

These are factors which may accentuate the relative increase in density of the necrotic head. The density of the head shown in Fig. 8 is both relative and actual and is probably due to all the causes which have been presented.

COLLAPSE

This second gross characteristic of aseptic necrosis in the femoral head occurs obviously from structural weakness. It is in every case a complication of mechanical stress to which the head has been subjected, generally in weight-bearing. Examination of histologic sections again shows a considerable variation in the basis for this weakness. Most commonly it would seem to be the consequence of multiple fractures through necrotic trabeculae made slender by resorption. The sections in Figs. 10 and 11 both show areas in which the trabeculae are thin and often spider-like, many of them fragmented. Another basis for collapse is evident in Fig. 9, which is a case of caisson disease. There has been infarction with complete resorption of an extensive area of bone structure and replacement with fibrous tissue which has collapsed. Figure 10 illustrates still another situation. This case, assumed to be a fissure fracture, shows large plates of proliferating cartilage in the substance of the head, with loss of its structural integrity and collapse. Planes of fibrous tissue may similarly



Fig. 8.—Increase in density of this necrotic head seemed both relative and actual when compared with the normal hip. The sharply outlined fragment suggests osteochondritis dissecans (see Fig. 11).



Fig. 9.—Cross section of resected femoral head in caisson disease (see Fig. 4), showing the effects of infarction with massive areas of bone resorption and fibrous tissue replacement. Most of the bone is dead and fragmented. The bony trabeculae in the lower portion of the section have been remodeled and are much larger than average in size and would appear denser on the roentgen film.



Fig. 10.—The upper portion of this necrotic head is separated from the lower portion by a complete band of proliferating cartilage. Extension of the cartilage into the adjacent bone is visible. Much of the bone is thin and fragmented, while some of the trabeculae are thickened (Case 1, Fig. 14).



Fig. 11.—Cross section of resected femoral head (case shown in Fig. 8). Extensive necrosis of the upper portion of the femoral head is evident. The trabeculae are thin and fragmented in some areas, while in others they are thickened. A dense fibrous band, evidently the site of fracture through the weakened trabeculae, separates the more necrotic upper portion from the lower area where much of the dead bone has been resorbed. The upper portion appears as a dead fragment on the roentgen film. The articular cartilage is fairly well preserved.

the head, generally forming along fracture lines through the necrotic trabeculae or at the junction of necrotic bone at the apex of the head and an advancing zone of creeping substitution (Fig. 11). In Gaucher's disease extensive resorption of necrotic bone may produce collapse. Bone replacement does occur, but often so slowly that there are areas which present only the fibrous framework of the bone.

Osteochondritis Dissecans

The third roentgen characteristic has been referred to as the appearance of osteochondritis dissecans. A diagnosis of osteochondritis dissecans in the femoral head is made with fair frequency when actually true osteochondritis dissecans probably occurs only rarely. The term should be restricted to a condition where there is a small circumscribed area of necrotic bone at the articular surface separated by connective tissue or fibrocartilage from an otherwise viable head. When the diagnosis is made roentgenographically, further investigation generally proves that the adjacent portion of the head is also necrotic. Figure 8 illustrates such an instance of a necrotic body in a necrotic head. This picture of a sharply defined necrotic ossicle is probably generally the result of a fracture through the necrotic trabeculae from pressure against the rim of the acetabulum, separating a small segment of the subchondral bone. Occasionally the fracture may be at the junction between necrotic and recently formed living bone. The fractured fragment is separated from the rest of the head by connective tissue and with continued weight-bearing this connective tissue zone becomes more mature (Fig. 11 shows such a zone). Continued motion from walking may establish the equivalent of a nonunion between the fragment and the head. Occasionally a proliferating plate of fibrocartilage originating perhaps in a fissure fracture may sharply demarcate a fragment from the dead head and will resemble osteochondritis dissecans on the film (Figs. 10 and 14).

Not uncommonly on the articular surface of a reorganizing necrotic head, a cup-shaped defect will be seen roentgenographically. This is generally at the fovea, and is presumably from revascularization and resorption by the foveal vessels. In this defect new bone may be laid down while the rest of the head is still necrotic. This produces a picture of osteochondritis dissecans on the film but is pathologically the reverse of that condition in that there is a living ossicle in a dead head, rather than a dead ossicle in a living head. This is not an uncommon finding in Perthes' disease. Occasionally a necrotic ossicle may represent the last fragment in a reorganizing head.

Osteo-arthritis

The fourth and least characteristic roentgenographic change is osteo-arthritis. It results largely from the incongruity of the articular surface which results from collapse of the head. Of course, if the cartilage as well as the head has become necrotic as a primary result of loss of vascularity, then osteo-arthritis, like the necrosis itself, would be a primary process. In many of our specimens, however, the cartilage was surprisingly well preserved, even when some collapse of the head had occurred. Figure 12 shows the irregular contour of the head in a case of caisson disease with collapse. The articular cartilage lies in folds on the

irregular head and osteo-arthritis is inevitable. Figure 10 also shows the infoldings of the articular surface.

In this context we might mention the frequent cases of unexplained severe osteo-arthritis of the hips, especially those which are unilateral. It seems likely that these generally represent an aseptic necrosis in which the arthritic change overshadows the other characteristics. These hips, frequently with areas of resorption in the subchondral region on the roentgen film, on pathologic examination are often shown to have extensive areas of aseptic necrosis.



FIG. 12 —Femoral head in caisson disease. The surface is irregular and the degenerated articular cartilage lies in folds on the surface.

DISCUSSION

Necrosis of the femoral head is probably never absolutely sudden and complete. Even in the most abrupt and complete interruption of the circulation some elements of the head must die before others, even though all may die quickly. But in some instances the interruption of the circulation seems gradual and the process of necrosis is greatly extended. In the cases which served as the basis for this review, the evolution of aseptic necrosis of the hip seemed to follow two general patterns (Fig. 13), one representing abrupt interruption in the blood supply *to* the head, resulting in rapid and extensive necrosis, while the other was a more gradual process which originated perhaps *within* the head and produced a slowly advancing necrosis. In the latter instance it appeared to progress almost like a tumor, from its own pathologic momentum, to involve gradually the entire structure of the head.

It must be pointed out that the changes which developed rapidly, and those which progressed slowly all ultimately presented the same gross characteristics.

The more rapid process would apply to fractures of the femoral neck in which the entire circulation might be suddenly interrupted (Fig. 2), or to dislocations with the same vascular damage (Fig. 3). In caisson disease, the effect of liberation of large volumes of nitrogen in the rigid structure of the head and neck of the femur might also completely occlude the vessels as effectively as if they were ruptured.

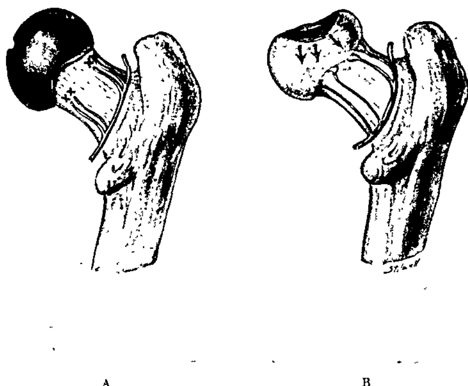


Fig. 13.—Patterns in development of aseptic necrosis of the hip. (A) indicates the result of sudden complete interruption of the blood supply *to* the head, while (B) shows a slowly progressive necrosis which seems to originate *within* the head.

In Gaucher's disease, on the other hand, this process of occlusion may advance much more slowly. More typical, however, of the second group were those which developed in fractures of the femoral neck, long after union (Fig. 6A), or in dislocations of the hip which developed changes several years later. It seems also to apply to those cases which have been referred to as idiopathic. These included the 3 ballet dancers and the acrobat, with presumed traumas of undetermined nature.

Three patients, already referred to, gave a history of rather severe direct trauma to the hip but without immediate roentgen evidence of fracture. All of these patients have been followed for some years and their histories seem of sufficient interest to be presented in some detail.

Case 1. Female, aged 58, was first seen 18 months after injuring her left hip in a fall. Because of severe pain she had been hospitalized elsewhere for some weeks after injury. Weight-bearing was gradually resumed and she was able to get about quite readily with moderate pain in the hip area. The pain gradually increased in degree until at the time she was first seen by us, 18 months after injury, she was able to walk only two blocks with considerable discomfort and an obvious limp. Examination disclosed markedly restricted and painful motion of the hip. Roentgenograms (Fig. 14A) showed a depressed fragment of femoral head, obviously denser than the balance of the head, interpreted as a necrotic, ununited, subchondral fracture of the head with secondary osteo-arthritis.

A trochanteric arthroplasty was performed shortly after the patient was first seen, using a vitallium cap (Fig. 23). This provided improved motion and excellent relief from her pain. Two and a half years after operation the result is still excellent.

The operation supplied for study the entire femoral head, cross sections of which are shown in Figs. 10A and 14B. This cross section corresponded to the roentgenogram and revealed an irregular, wedge-shaped, solid fragment of bone separated from the neck by an irregular plate of cartilage which spanned the entire width of the bone. The structure of the neck was friable and obviously also abnormal. Several islands of cartilage were evident in the bone structure in addition to the large plate.

Microscopic section (Fig. 10) disclosed the wedge-shaped fragment at the apex of the head to be composed of necrotic bone and necrotic connective tissue. The layer of cartilage which separated this fragment from the neck was a mixture of hyaline and fibrocartilage, some of it proliferating actively. The bone of the neck was also largely necrotic. Irregular areas of cartilage were present in the subchondral bone and in the neck. These were all continuous with the thick cartilagenous band. The articular cartilage had almost entirely disappeared.

The general pathologic diagnosis was fracture of the femoral head with chondrification and cartilage proliferation at the fracture site.

Case 2. Male, aged 33, admitted to the hospital with pain in the left hip of several months' duration. It was moderate in degree and had come on rather suddenly. Ten years previously he recalled a direct injury to the hip in a fall. He was disabled for several days at that time, but made a complete recovery. Roentgen films disclosed a fairly regular zone of diminished density in the center of the neck, surrounded by an area of slightly increased density. The form and structure of the head otherwise seemed normal (Fig. 15A). The possibility of an osteoid osteoma, eosinophilic granuloma, or chondrosarcoma was considered and the patient was admitted for biopsy. Through a window in the neck overlying the lesion some bony tissue was removed for study.

Microscopic examination of the removed material disclosed fragments of necrotic bone in a mass of fibrous tissue, with some new bone deposition on the old trabeculae adding to their thickness. Adjacent to the bone was an uneven area of cellular fibrocartilage. The picture was that of regenerating necrotic bone. At first glance the presence of proliferating cartilage had suggested a diagnosis of chondroma.

Following operation the patient continued to have pain in the hip, gradually increasing in degree with progressive restriction of motion. Roentgenograms made one year after operation showed mottled increase in density of the femoral head with slight irregularity (Fig. 15B). In another year the picture of aseptic necrosis was complete, with marked increase in density, collapse, and demarcation of a bony fragment at the articular surface (Fig. 15C). At that point, in view of the old history of injury, a diagnosis of subchondral fracture with aseptic necrosis was made.

Case 3. Female, aged 50, employed as a hospital attendant. She slipped while at work and sustained a direct injury to the hip. There was considerable immediate pain, but roentgen films of the hip were negative for fracture. The pain largely subsided and she was able to continue with her regular duties. Some months later the pain increased in degree but was not incapacitating. One year after injury roentgenograms for the first time disclosed abnormality. This was in the form of increase in density, collapse, and separation of a fragment from the evidently necrotic head (Fig. 16). The patient has declined surgical treatment and chooses to maintain a nonweight-bearing regime in the hope of some reconstitution of the head.



Fig. 14A.—Case 1: extensive necrosis of the femoral head with what appears to be a depressed fracture fragment.

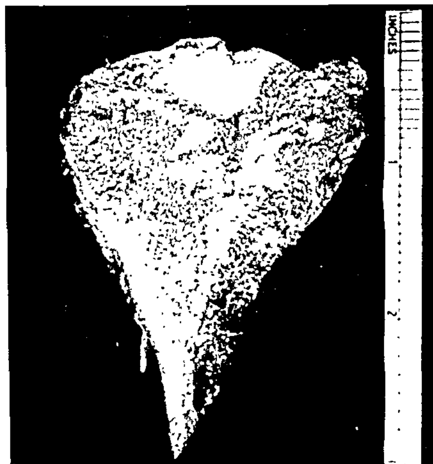


Fig. 14B.—Cross section through the removed head, showing an irregular transverse band of cartilage. Extensions of the cartilage into the adjacent bone cannot easily be seen in this photograph (see Fig. 10).

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Fig. 15B.—Case 2: 15 months after the onset of symptoms. Note the increased density and beginning collapse of the head.



Fig. 15C.—Case 2: Two years after the onset of symptoms. There is advanced aseptic necrosis with collapse and demarcation of a subchondral necrotic fragment.



FIG. 15A.—Case 2: Three months after the onset of pain. Normal form except for a circular area of diminished density in the center of the neck.

The histories in these 3 cases seem to indicate that the development of the change in the femoral head was initiated by a direct trauma to the hip without gross evidence of fracture. The possibility of contusion or fissure fracture through the articular surface is certainly suggested as possibly initiating the sequence of events which followed. J. A. Key's discussion on contusion of the articular cartilage suggests the significance of this type of injury in the production of painful joint pathology. In his cases, however, the effect was evidently assumed to be largely confined to the cartilage, and removal of the damaged area produced relief.

Much more significant in relation to aseptic necrosis of the femoral head are the observations of Shigeo Nagura, a Japanese investigator. He reports in great detail a research study into the production of aseptic necrosis in Perthes' disease. He assumed that aseptic necrosis may in some instances represent a complication of the normal process of repair following relatively minor injuries. On the basis of this assumption, he produced minor defects in the femoral heads of rabbits by multiple punctures through the articular cartilage with a scalpel. Examination of the femoral heads at various intervals disclosed the progressive development of extensive necrotic changes from these minor injuries. Necrosis occurred, however, only if weight-bearing was permitted. His interpretation of the sequence of events which he observed was ingenious. He pointed out that the narrow clefts which he created rapidly filled in with young connective tissue. Fibrocartilage

soon formed in the connective tissue. Left undisturbed, the cartilage would be transformed into normal bone by enchondral ossification. Instead, under the influence of weight-bearing, this young cartilage was stimulated to proliferate actively and even aggressively, actually producing secondary defects and invading the adjacent bone until the structure of the head became so weakened by the proliferating cartilaginous plates that it collapsed. Areas of bone were isolated by this process and became necrotic until the whole head was destroyed. Figure 17 is a diagrammatic representation of the process.

Nagura later extended his explanation to apply to forms of bone necrosis other than Perthes' disease, and was able to produce the same effects with dull traumas as well as with sharply localized injuries. So convinced was this investigator that he declared dogmatically that all other theories were incorrect. "The cause of aseptic necrosis of bone is found in traumas which sever the continuity of the subchondral bone, followed by cartilaginous proliferation into the spongiosa."

The 3 cases reported above offer some support of Nagura's theory. Most significant is the nature of the initial trauma in all 3 cases and the slow development of clinical evidence of necrosis. In 2 of the cases the necrotic bone was examined and contained areas of cartilage. This was particularly true in Case 1 where the pathologic section disclosed extensive areas of proliferating cartilage throughout the bony structure of the head, intermingled with large areas of necrosis of bone (Fig. 10). The section closely resembles some of the illustrations in Nagura's own work (Fig. 18).



FIG. 18.—An illustration from one of Nagura's papers. The cartilaginous zone (AZ), extending from the articular surface into the necrotic bone, is similar to the zone in Fig. 10. (AZ indicates *Abgrenzungzone* or zone of demarcation.)

(*Zentralbl f. Chir*, 1938.)

Fig. 16.—Case 3: One year after direct injury to the hip without evident fracture. There is advanced aseptic necrosis with collapse.

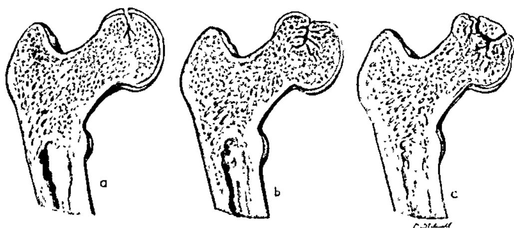


Fig. 17.—Diagram of progression of aseptic necrosis following an osteochondral fracture (Nagura). The last stage resembles the findings in Case 1 (Figs. 10 and 14).

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The validity of Nagura's observations has not, to our knowledge, yet been confirmed. Also, it is certain that aseptic necrosis of bone in experimental animals develops more readily than in humans. He does make some observations on adult human bone and if his conclusions are correct, even in part, they offer a basis for the understanding of many cases of aseptic necrosis of bone, especially in the femoral head. We might also consider, in relationship to this theory, dislocations of the head of the femur with fissure fractures produced by impaction against the rim of the acetabulum (Fig. 3), and perhaps even some fractures of the femoral neck with slowly developing necrosis.

Before discussing the question of treatment we might restate our premise that aseptic necrosis is a basic alteration in the organization of the femoral head. It may originate from totally different causes but proceeds in various ways to essentially the same structural end-result. It is this final *form* and the mechanical symptoms which it produces which we are called on to treat, more than the etiology which may have initiated the changes. Roentgenograms of 8 cases of aseptic necrosis representing substantially different etiologies are shown together to demonstrate their uniform structural character (Figs. 19A to H).

TREATMENT

The gross alterations in the form of the femoral head after collapse has occurred are irreversible and, in general, incompatible with free or painless function. Severe degrees of osteo-arthritis are an inevitable consequence, and the patient eventually requires relief. If the aseptic necrosis had been identified before collapse then it might have been plausible to eliminate weight-bearing, in the hope that creeping substitution would restore the head. This is a rare opportunity because the first symptoms, except in fractures, are often the result of collapse. There is moreover a real question as to how often the adult femoral head is capable of complete restoration, and the practical problem of how long it would require. In fractures of the femoral neck with aseptic necrosis, omission of weight-bearing may allow a necrotic head to go on to union without collapse. *Here again, what dependable criteria are there for adequate structural repair* of the head? Phemister suggests long periods of nonweight-bearing, but for security how many years should this be? It seems rare for a necrotic adult femoral head not to go on to ultimate collapse, particularly after fracture, even if the outlook for a time appears favorable. This has been the rule in our cases.

In dislocations of the hip the possibility of aseptic necrosis is generally recognized, even though it seems that the incidence is not as great as had previously been supposed. It has been the practice of many surgeons to defer weight-bearing on the affected hip for six to 12 months. This might be of substantial help in permitting repair of a fissure fracture, but if there has been actual disruption of the arterial supply this period of time would seem completely inadequate. In dislocation of the hip we have found no early guides to whether necrosis will or will not occur, and in simple dislocations where necrosis is infrequent, it seems unreasonable to forbid weight-bearing prophylactically for more than six months.

With the collapse of the head and increasing osteo-arthritis, pain and limitation of motion generally become severe. The degree of disability may be great, and



FIG. 19A.—Female, aged 26; Gaucher's disease.



FIG. 19B.—Female, aged 32; idiopathic (ballet dancer).



Fig. 19C.—Female, aged 22; healed fracture of the neck.



Fig. 19D.—Female, aged 58; fissure fracture of the head.



FIG. 19E.—Male, aged 25; idiopathic (high altitude flyer).

FIG. 19F.—Male, aged 34; caisson disease.



Fig. 19G.—Male, aged 33, subchondral fracture.



Fig. 19H.—Male, aged 30; Gaucher's disease.

if relief is to be provided drastic measures are required. Of course, the patient may prefer to employ crutches and through their use, continuously or intermittently, procure sufficient comfort to satisfy his wants. Most patients, however, demand greater freedom and prefer to walk unencumbered. To accomplish this end various surgical measures have been resorted to. Those which have been employed in the cases which have been the basis for this discussion will be illustrated. The technics are standard and will not be discussed in detail.

Neurectomy

Resection of the articular branches of the obturator and sciatic nerves to the hip has been performed alone and in conjunction with acetabuloplasty. The relief which has been afforded in a small series was discouraging. Only one case was provided with substantial benefit.

Arthrodesis

Arthrodesis offers a reliable measure for the complete relief of symptoms in unilateral cases. The loss of motion is a disadvantage, but it affects the gait surprisingly little and in working men offers a strong dependable extremity. Figure 20 illustrates a case of a laborer who has resumed his regular work with little limitation following this procedure.



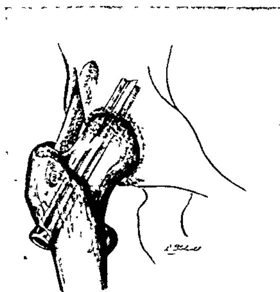


Fig. 20.—Arthrodesis of the hip, intra-articular and extra-articular, employing a Smith-Petersen nail to maintain position. The nail was removed when union was complete.

ARTHROPLASTY

Vitallium cap arthroplasty of the femoral head was employed in a considerable number of these patients. Many of the results were excellent but many were not satisfactory. Our estimate would correspond on the whole to the findings at the Mayo Clinic and those of others in which only approximately 50 per cent of results were considered satisfactory. The case illustrated had a particularly favorable outcome with relief of pain and excellent motion (Fig. 21).

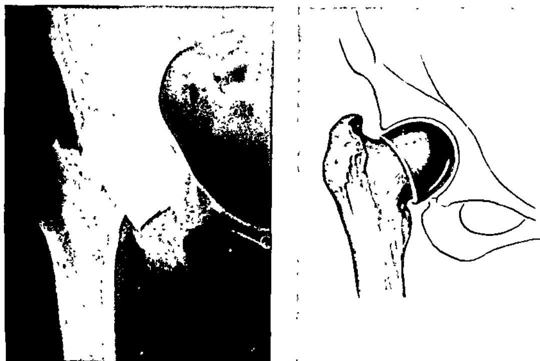


FIG. 21.—Vitallium cap arthroplasty of the femoral head. Recently nylon caps have been used at the Hospital for Special Surgery in place of vitallium.

The *Colonna operation* performed in a few younger cases provided satisfactory results (Fig. 22).

More recently, this procedure has been modified by Philip D. Wilson and a vitallium or nylon cap has been placed over the trochanter following resection of the head and neck. A substantial portion of the trochanter including the gluteal attachments is transplanted downward (Fig. 23). This method was employed in 20 of these cases including 2 cases of Gaucher's disease.

The procedure has generally proved more satisfactory than the arthroplasties of the head. It has permitted more substantial removal of the pathology, and the percentage of relief of symptoms has been high. One of the cases of Gaucher's disease so treated was seen recently, five years after operation. He was getting

about freely without pain, and the result was obviously satisfactory. A good range of motion was preserved in the hip (Fig. 23).

Hip arthroplasty utilizing a *prosthetic head* has been employed over the past few years. At the Hospital for Special Surgery the acrylic head devised by Judet has been used. In this method the head of the femur is cleanly removed and the stem of the mushroom-like prosthetic head is introduced into a channel in the neck prepared by a special borer. When necessary, the acetabulum is deepened.



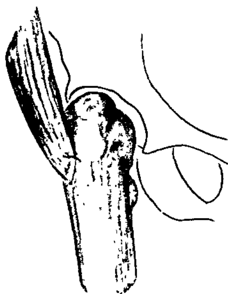


Fig. 22.—Colonna operation. The head and neck have been removed and the trochanter placed into the acetabulum which may be deepened if necessary. The attachment of the abductor muscles has been transplanted distally to maintain its tension.

Following this procedure the patients may be ambulatory without support in several weeks. The operation is easy to perform and the early functional results have been encouraging. Time is required to determine the durability of the results and whether the mechanical demands of this foreign head on the bone structure can be withstood (Fig. 24).

Other procedures have been devised for this condition, directed at repair of the damaged bone or restoration of the circulation. With these we have had little experience. The mechanical requirements of the situation seem to imply the need for major reconstruction of the hip joint or arthrodesis, and it is unlikely that more conservative measures will generally provide much relief.

ARTHROPLASTY

Vitallium cap arthroplasty of the femoral head was employed in a considerable number of these patients. Many of the results were excellent but many were not satisfactory. Our estimate would correspond on the whole to the findings at the Mayo Clinic and those of others in which only approximately 50 per cent of results were considered satisfactory. The case illustrated had a particularly favorable outcome with relief of pain and excellent motion (Fig. 21).

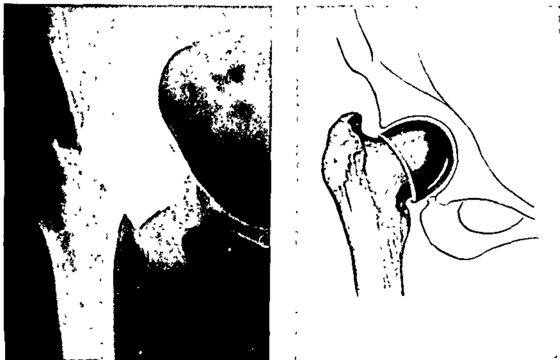


FIG. 21.—Vitallium cap arthroplasty of the femoral head. Recently nylon caps have been used at the Hospital for Special Surgery in place of vitallium.

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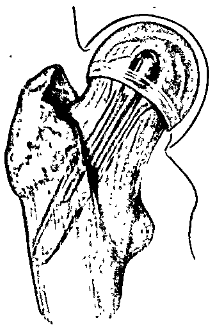


FIG. 24.—Acrylic replacement of the femoral head.

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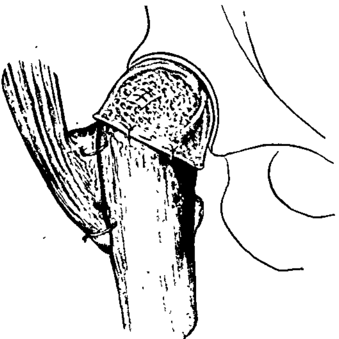


FIG. 23.—Trochanteric arthroplasty. The greater trochanter with its muscle attachments has been set down. In the drawing, a nylon cap has been used in place of the vitallium.

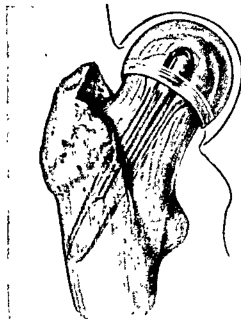



Fig. 24.—Acrylic replacement of the femoral head.

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Arthroplasty

ROBERT A. KNIGHT, M.D.

INTRODUCTION

Mobilization of the stiffened joint has been one of the most intriguing problems of bone and joint surgery for the past century. It has been, and still is, one of the more difficult operative procedures. The relative number of suitable cases available has been far less than for the majority of other bone and joint procedures, the obstacles to be overcome greater, and, in general, the results have been more discouraging. Thus, it is a surgical procedure which has never met popular acclaim until recent years, its use having been confined to a few large clinics and to relatively few master surgeons. Even at the present time, it is a sufficiently difficult procedure and unsatisfactory results and failures occur frequently, so that it should be employed only by those surgeons well grounded in the selection of cases for operation as well as in the actual operative technic and postoperative care. It must be stressed that the most successful operative procedure will fail unless detailed and prolonged after-care is given, for the operation itself is only one episode in the over-all picture.

The successfully mobilized joint must have stability, endurance, and relative freedom from pain as well as a satisfactory range of motion. In a joint resection, motion is gained by wide removal of bone at the expense of stability and joint control, thereby differing fundamentally from a true arthroplasty. Stability is more essential to a joint than motion, particularly in a weight-bearing joint, and it is because of this feature that arthroplasty has survived and resection has fallen into disuse.

HISTORY

In 1826, J. Rhea Barton of Philadelphia reported a case in which a cervicotrochanteric osteotomy was performed for ankylosis of the hip joint; repeated manipulations were carried out to prevent reankylosis. Despite these manipulations, however, the ankylosis recurred after two years. In 1840, Rodgers of New York performed a similar procedure in the intertrochanteric region but excised a disk of bone at the same time; the end-result was said to be excellent. The earliest case in which a true resection or excision of a joint for ankylosis was performed was that of Textor who, in 1843, reported the successful mobilization of an ankylosed elbow. Ferguson, Czerny, Sayre, and Delfontaine reported cases in which a similar procedure was performed, while Dartignes, in 1900, described a trochlear type of osteotomy in which the joint surfaces were resected but their form preserved.

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To the late John B. Murphy of Chicago must go the credit for the development of the fascial flap method which is the foundation of the modern arthroplastic measures in the knee, elbow, and metacarpophalangeal joints. The essential feature of his operation, introduced in 1902, is the insertion of a pedicled flap of fatty tissue and fascia taken from the vicinity of the operated joint. Murphy believed that the transplant received nourishment through the pedicle and insisted on the inclusion of a considerable quantity of fatty tissue, reasoning that the fat aids in laying the foundation of the new joint by the formation of a hygromatous bursa. It is of interest to note that Albee, as late as 1933, stressed the importance of utilizing fat as well as fascia, reasoning, as did Lexer, that the fat exerts a hemostatic influence on bone as well as helping to fill the newly formed joint so completely that a postoperative hemarthrosis cannot develop.

Kirschner, in 1909, advocated the trial of free fascial grafts in joints mobilization, and in 1910, at his suggestion, Payr performed an arthroplasty of the knee using a free graft of fascia. Shortly thereafter, Putti, Rehn, Ritter, and the MacAuslands adopted this method. Putti, Campbell, the MacAuslands, and Henderson, though contributing no truly original features to the operation, performed large numbers of the procedure in the various joints, greatly improving and refining the operative technic, and defining the indications and contraindications. These men are to a large extent responsible for the present-day stature of the procedure. Smith-Petersen, through his fundamental work on a metal mold, has revolutionized the procedure of arthroplasty of the hip, extending its field of indications and emphasizing the occasional necessity for later revision of an arthroplasty where initial motion is gradually lost; revision is particularly indicated where the procedure has been performed for atrophic or rheumatoid arthritis. Alexander Gibson, of Winnipeg, has modified Smith-Petersen's method, utilizing a variant of the Kocher approach and attacking only the femoral head in cases where the acetabulum is preserved. Since Gibson described his method in 1948, the long-term results are not yet available, though at present Gibson's results are most encouraging.

INDICATIONS AND CONTRAINDICATIONS FOR ARTHROPLASTY

In general, arthroplasty is indicated only in the hip, knee, temporomandibular, elbow, and metacarpophalangeal joints. Elsewhere, the anatomic make-up of the joints is such that good results are not ordinarily obtained and, more important, loss of motion in these joints is so satisfactorily compensated by adjacent functioning joints that ankylosis in good position is to be preferred. As an example, an ankle fused in good weight-bearing position, compensated by midtarsal and tarsometatarsal joint motion, results in far less disability than an arthroplasty

As the method of joint mobilization gradually evolved, the desirability of interposing some material between the bone ends and the importance of stability of the mobilized joint became evident. Modern arthroplastic methods, then, can be said to differ from the earlier procedures in the use of an interposing substance between the bone ends and in the more exact remodeling of the joint ends.

The materials used for joint interposition have been of three types: foreign heterogenous substances, both absorbable and nonabsorbable, animal membranes, and materials of human source. To the first type belong wood, various types of metal, celluloid, ivory, rubber, gutta-percha, and temporary packings of gauze and nylon. Collodion and decalcified bone were also used. With the exception of nylon and metal, all of these substances failed. Kuhn has recently reported the successful use of nylon in arthroplasty of the knee. The mold arthroplasty, employing a cup of vitallium, was evolved in 1937 by Smith-Petersen. This method has revolutionized the procedure for mobilizing the hip joint and will be discussed in detail later in this section.

Föderl in 1895 reported the use of animal membrane and walls of ovarian cysts as interposing materials, but suppuration developed with recurrence of ankylosis in these cases. In 1913, Diel reported a case in which a flap of reindeer tendon and the epiploon of a rabbit were used successfully, but it was not until Baer devised his method of using chromicized pig's bladder that animal membranes were used with enthusiasm. This method, like its predecessors, has also fallen into disuse.

In 1863, Verneuil suggested the possibility of interposing soft parts of autogenous origin in an attempt to obviate the risk of sepsis and extrusion of the material from the joint. Rochet covered the ends of the resected bones with periosteal flaps, reporting this method in 1896, and later Hofmann and Grierfenhagen reported cases in which this method was used successfully. Payr and von Frisch, however, were unsuccessful with this method, and the use of periosteum was gradually discontinued. Joint cartilage was tried to some extent, with numerous successful results, especially those of Tuffier, Jacob, Weglowski, Klapp, Deutschlander, and Mauclaire. Judet, in 1908, reported his experimental work on the transplantation of cartilage, concluding that joint cartilage, when it was separated from an organism and reapplied to a properly selected and prepared structure, could unite and continue to live. It was evident to him that a purely cartilaginous fragment united with difficulty, but when it was reinforced with a layer of bone, union followed in the majority of cases. The fundamental importance of Judet's work was not appreciated until recently when J. R. Moore introduced his "cartilage-cup arthroplasty." The behavior of the cartilage cup fully substantiates Judet's conclusions. Delagenière, in 1917, concluded from a study of free cartilage grafts that a stable joint could not be obtained by their use and the interposition of cartilage grafts was gradually abandoned.

Transplants of skin, muscle flaps, and muscle grafts have also been utilized. Muscle flaps have been used particularly in the mobilization of ankylosed jaws, probably because of the ease of interposing a flap of masseter muscle into the resected joint, in contrast to the difficulty of interposing satisfactorily a flap of muscle into the other larger joints. Muscle is bulky, necessitates the resection of a rather large amount of bone, and undergoes degeneration rapidly.

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of the ankle. In this joint, the end-results of arthroplasty have been, in general, most unsatisfactory and undependable. Likewise, a painless fused wrist gives far better function and strength than one in which partial motion has been regained by arthroplasty but which is weaker than normal, somewhat painful with prolonged or heavy use, and limited in its endurance; again, the functional result following arthroplasty of the wrist is usually disappointing.

Even in the joints in which arthroplasty may be employed, it is essential to select the cases carefully, for operation is not advisable in every ankylosed joint. The following factors must be taken into consideration in each case before advising arthroplasty.

(1) The most satisfactory results have been obtained where ankylosis has *resulted either from an acute pyogenic infection of the joint or from trauma.* With the present-day use of antibiotics, the number of cases of joint ankylosis resulting from an acute pyogenic joint infection have become exceedingly infrequent. On the other hand, the incidence of partial or complete ankylosis resulting from trauma is increasing.

(2) Where ankylosis is the result of an acute infection, the infection must have been completely quiescent for at least six and preferably 12 months. Sepsis following surgical interference, particularly when due to relighting of a dormant infection, is the chief complication of arthroplasty. It is indeed fortunate that the use of appropriate chemotherapeutic and antibiotic agents has greatly decreased the incidence of this complication. Nevertheless, the rule of allowing an adequate lapse of time to follow complete subsidence of the infection should not be violated.

(3) Except where there has been a complicating infection, complete ankylosis due to trauma is seldom seen, even in the case of the elbow joint. Not infrequently, however, arthroplasty may be indicated in a painful joint with limited motion as a result of trauma and the development of a secondary traumatic arthritis. One example of this is the partially ankylosed elbow joint which has resulted from a severely comminuted condylar fracture of the elbow, wherein at the time of original injury it was impossible to reassemble the multiple small articular fragments of the humeral condyles into anatomic position. Another example is the painful hip of limited motion and endurance which has followed a fracture-dislocation, with or without complicating aseptic necrosis of the femoral head. The procedure may be indicated when motion is blocked because of comminution of the articular surfaces, even though pain is not a prime factor.

Occasionally, a joint may become ankylosed as a result of an adjacent extensive and deep burn. If arthroplasty is indicated in such an instance, it is essential that the soft tissues covering the joint be satisfactory; in almost all cases, preliminary skin grafting must be done to provide an adequate covering of skin and subcutaneous tissue.

(4) If there are multiple ankyloses resulting from a pyogenic infection of multiple joints, motion may be restored to the desired joints if all infection has subsided over a period of 12 months and if the adjacent bone is in good condition. Multiple ankyloses, however, make the postoperative rehabilitation of joint function more difficult so that the prospect of restoration of function in a given joint is less favorable than when the ankylosis is confined to a single articulation.

(5) Arthroplasty is contraindicated where ankylosis is the result of tuberculosis. The probability of relighting a latent tuberculous infection is so great and the serious consequences which may follow are so disastrous that the operation is not justified. The field of specific chemotherapy and of the antibiotics is being so rapidly expanded that there is the distinct possibility that in the foreseeable future a drug may be developed which will destroy the tubercle bacillus, making arthroplasty of a joint fused as a result of tuberculosis a safe and sound procedure. For the present, however, tuberculosis must be considered as a definite contraindication to arthroplasty.

(6) Arthroplasty may be attempted in the joint ankylosed by multiple atrophic or rheumatoid arthritis. Smith-Petersen now advocates that reconstructive procedures in arthritis be performed relatively early in the course of the disease while the para-articular tissues are in a more favorable condition and the bones are of more normal structure. The operation should be performed while the disease is under control, preferably during a remission induced by cortisone or ACTH therapy and before the disease has progressed to the extent that the muscles about the joint or joints to be mobilized have become fibrosed and markedly atrophic. After wound healing has occurred, drug therapy should be resumed and intensive rehabilitation of the operated joint is instituted.

(7) All other considerations being equal, the result following arthroplasty in a joint ankylosed in good functional position will be superior to that which follows mobilization of the same joint from an unfavorable position of ankylosis. If, for example, a knee is ankylosed in a position of 90 degrees flexion for many years, a preliminary osteotomy and capsulotomy should be performed, allowing weight-bearing for a sufficiently long period of time to restore bone density to normal and to allow the musculature of the extremity to regain its function. When this condition is obtained, arthroplasty may then be done with much greater assurance of a good result.

(8) If the destructive process causing the ankylosis has also resulted in impairment of growth because of damage to the epiphyses, or if there is excessive diminution in leg length from loss of continuity, the degree of function which may be restored by arthroplasty probably will be insufficient to warrant the procedure.

(9) The structure of the bone in the vicinity of the joint to be mobilized, as demonstrated roentgenographically, must approach normal (Fig. 1). Eburnation of the bone for a considerable distance from the site of operation, usually the result of an old hematogenous osteomyelitis, is a contraindication to arthroplasty. Such bone bears the same relation to normal bone that scar tissue bears to normal soft tissue. This dense bone provides a poor matrix for the reconstruction of a joint and, in addition, there is a definite possibility of relighting the old infective process, even though an adequate antibiotic coverage is provided prior to as well as following operation. In the knee region, dense bone almost always constitutes a definite contraindication to arthroplasty.

On the other hand, osteoporosis or atrophy of disuse also interferes with the bone remodeling necessary in performing an arthroplasty. In the presence of such a condition, active use of the extremity for a period of at least six months is necessary in order to overcome the osteoporosis and allow the bone structure

to return as nearly as possible to normal. This, as mentioned above, also allows preliminary redevelopment of muscle tone and function and a return of soft tissue turgor to normal. If malposition interferes sufficiently with the use of the extremity, bone atrophy will persist until correction of the deformity places the part in a position for development of function and restoration of weight-bearing. If the period of disuse has been so long that a medullary canal has been developed across the joint, it is usually impossible to develop sufficient bone through function to form a satisfactory joint (Fig. 1).

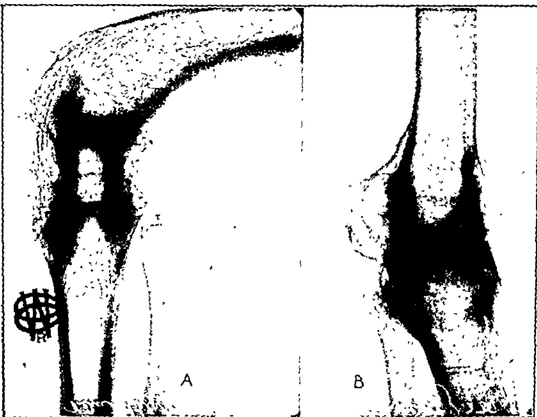


FIG. 1.—(A) The medullary canal traverses the joint line, unsatisfactory for arthroplasty. (B) Satisfactory for arthroplasty. Relatively normal density of bone.
(Speed, J. S., and Smith, H. [Eds.], *Campbell's Operative Orthopedics*, C. V. Mosby Co., 1949.)

(10) The most favorable age for arthroplasty is from that of bone maturity to 40 years, although in many instances the procedure may be justified in an older patient. This will depend on the occupation of the patient, his moral fiber, the outlook for the procedure as judged on the points mentioned above, and the patient's desire to have the procedure performed. In no instance, however, should the surgeon allow the patient to persuade him to perform the operation against his better judgment; invariably, he will regret it.

(11) The social status and occupation of the individual must be borne in mind. Arthroplasty is a selective procedure, particularly in weight-bearing joints. It is contraindicated in the weight-bearing joints of persons engaged in strenuous work, and is indicated only in those whose occupation and social status permit

primarily sedentary activities. Excessive obesity must be corrected prior to operation. Arthroplasty of the elbow has a somewhat wider range of indications, for an ankylosed elbow forms an extreme handicap, and the stability so necessary for a weight-bearing joint is of less importance. This also is true in the case of the temporomandibular joint.

TECHNIC OF ARTHROPLASTY

The technic of operation varies in the individual joints, taking into consideration their anatomy and function, as well as individual features of the ankylosis and the soft tissue status of the particular case. In the hip, the reconstruction more closely approaches the normal joint than elsewhere, while in the knee and elbow the reconstruction of a simple monocondylar joint is to be preferred. In the latter joints, the attempt to approximate the contour of the normal joint more closely may complicate the procedure and actually diminish the prospect of success of the operation. For the knee, one large femoral condyle and a shallow concave upper tibial articular surface form a hinge joint which will meet the requirements of function. It has not been found possible or even desirable to preserve the intra-articular ligaments.

The procedure may be considered as having four parts: (1) plastic adjustment of the soft tissues, (2) reconstruction of the bone, (3) interposition of metal or tissue between the bone ends, and (4) after-care.

Plastic Adjustment of the Soft Tissues

If contraction of tendons, fasciae, and capsule has occurred, it will be necessary to correct the soft tissue deformity as a preliminary procedure, unless the contraction is of relatively mild degree. At the time of operation, the incision must be planned with due regard to the anatomic relationship of the tendons, fasciae, nerves, and vessels. Operative approach to the joint must be made with the least amount of trauma in order to minimize the operative reaction as well *as to permit early wound healing and joint mobilization.* If soft tissue contractures are of mild degree, tendons should not be divided until the bone has been severed and remodeled, for it is quite frequently found that after the bone has been remodeled soft tissue contractures of mild or moderate degree do not require correction. If tendons, fasciae, or capsular structures do need lengthening, this should be done in a plastic fashion so that free function will not be impaired.

Reconstruction of the Bone

The joint ankylosis, whether osseous or fibrous, should be divided under direct vision. Force, if used at all, should be applied carefully, since crushing of the articular surfaces and fracture are always possibilities. The amount of bone which should be removed will vary with each joint and in the same joint, according to the individual operative findings. An adequate amount of bone should be removed during the remodeling procedure to permit free motion of the joint on manual traction, but under no circumstances should the amount of bone removed be so great that an adequate foundation for a functional joint is lost, regardless of the degree of contracture present. Rather, any severe soft tissue

contracture must be corrected in a plastic fashion prior to the arthroplasty. Excessive removal of bone will, in effect, result in a joint excision rather than an arthroplasty. An example of this is found in the elbow where the expanded lower extremity and humeral condyles are removed. In this instance, only the shaft articulates with the radius and ulna, and a flail pseudarthrosis is the outcome.

The involvement of multiple joints makes rehabilitation of the operated joint less efficient. Such a joint tends to lose part or all of its motion during the rehabilitation of subsequently mobilized joints. For this reason, more bone should be excised than in an arthroplasty of a single joint. This is permissible, since the aim in this type of case is different from that in which only one joint is to be mobilized.

Interposition of Metal or Fascia

Interposition of tissue between the bone ends is more necessary in some joints than in others, for the tendency to recurrence of ankylosis varies in the different joints. In the temporomandibular joint, it is not the practice at present to interpose soft tissue, whether fascia or muscle, since, as Henderson has shown, the articulation of the opposite side holds the surfaces apart in a unilateral ankylosis. In bilateral ankylosis of the jaw, gravity and the weight of the jaw serve this purpose. In the knee, elbow, and metacarpophalangeal joints, fascia has proved to be the interposing material of choice, while in the hip, the metal mold of Smith-Petersen has replaced fascia as an interposing substance. In the case of multiple ankyloses, where a fascia lata graft may not be available, and in patellofemoral fusion accompanied by free movement between the tibia and femur, the pedunculated fascial flap obtained by dissection of fat and fascia in the vicinity of the joint may be used.

The free fascia lata graft for elbow and knee arthroplasty is obtained from the outer aspect of the thigh, since the fascia in this region is most suitable for transplantation and a sheet of adequate size is easily obtained. For arthroplasty of the metacarpophalangeal joint, the thin delicate deep fascia of the inner or outer side of the thigh, the anterior aspect of the upper forearm, and the anterior aspect of the lower arm are superior to fascia lata. The majority of surgeons prefer to interpose two layers of fascia between the articular surfaces, the rough outer surface being placed against the bone so that the smooth, glistening surface will form the articulating surface.

After-care

As a general rule, the part is immobilized in a splint or plaster cast after operation, with traction applied to the part distal to the arthroplasty. Immobilization and traction are maintained until the wound is completely healed, usually 10 to 14 days. Active and passive motion is then instituted, using special apparatus suited to the particular joint and under the control of the patient. At the outset, fear of pain may inhibit contraction of the motor muscles, but this is gradually overcome by continued practice. Properly timed, planned, and carried out, function is gradually restored without intense pain. Violent and excessive exercise will induce a severe reaction and is injurious and incompatible

with good functional recovery. Where possible, supervised daily physical therapy is given, for active and powerful motion is more easily cultivated under the control of an expert. If such a therapist's services are not available, rehabilitation may be accomplished by having the patient follow carefully planned exercises, checked at regular intervals by the surgeon himself. It is important for the patient to be closely supervised during the first few months after operation in order to guide the joint in proper channels of function. Following arthroplasty of the hip, for example, it is necessary that a proper walking pattern be developed which employs the muscles in as nearly normal a fashion as possible and that motion be developed only as rapidly as muscle strength is developed to control the joint. With minor variations, the same is true of the other joints. Usually active and passive motion, developed synchronously, will give the best result. Too early weight-bearing is to be avoided. No rule of thumb for this can be given, weight-bearing being increased only as the density and strength of the bone approach normal in order to prevent absorption of the articular surfaces with consequent instability of the new joint.

If examination reveals excessive tenderness, pain, or swelling, rest is enforced until all active symptoms subside; thereafter, treatment and activity should be cautiously resumed. The integrity of the ligaments and strength of musculature is likewise checked, since a decrease of muscle power without inflammation is a definite danger sign. This usually indicates bone absorption, sequestration, or a stretching and increase in laxity of the ligaments. Roentgenograms should be made at intervals of two months during the first year. If there is increased bone absorption leading to instability, temporary protection of the joint with any necessary degree of curtailment of joint function is indicated. In the presence of osteoporosis, active function should be developed as rapidly as possible, preferably in conjunction with judicious physical therapy, but in the case of joints of the lower extremity, weight-bearing should be omitted or at least relieved until the density of the bone approaches normal. If, during the course of postoperative follow-up, passive motion is found to have increased more rapidly than the muscle power, the patient should be temporarily fitted with a brace which incorporates special joints to prevent motion of the joint beyond the desired degree.

Once active motion of 30 degrees or more has been developed, there is no further tendency to recurrence of ankylosis and the range of motion will tend to increase rather than decrease. On the other hand, if only a few degrees of active motion have been cultivated by the end of three months, recurrence of ankylosis is probable. Ordinarily, strenuous function is not to be encouraged until the end of one year following operation, for this length of time is required before muscle power, range of motion, joint stability, and bone density and integrity are satisfactorily developed. Rarely is it necessary or wise to perform joint manipulation under anesthesia following arthroplasty. In resistant cases, this may occasionally be done, but in such instances, no more than 20 to 30 degrees of increase in motion should be attempted at any one time. Efforts to gain more than this may lead to a severe postmanipulative reaction, with exudation and reorganization of inflammatory products, as well as the formation of more dense intra-articular adhesions. Forceful manipulation is absolutely con-

traindicated; not infrequently para-articular fractures have occurred as a result of this and in practically every instance compression and microfracture of the articular surfaces will take place (Fig. 2).



Fig. 2.—Supracondylar fracture was sustained as the result of vigorous manipulation in an effort to increase the range of motion following arthroplasty.

JOINT EVOLUTION FOLLOWING ARTHROPLASTY

Clinical or Functional Results

After operation, the appearance of the joint is changed. In the knee, for example, the patella and the lateral patellar sulci are usually not visible, the joint having a cylindrical shape. Active and passive joint motions are usually commensurate, though in some cases, varying with the quality of the musculature and the active rehabilitative efforts of the patient during after-treatment, passive motion may exceed active motion with ill effects. The muscle power will vary in different joints after restoration of function. In the elbow, the triceps may be weak and extension will be accomplished largely by gravity; in such an instance, the effect will not be deleterious except when the arm is used for overhead work. In the knee, full extension against gravity may be lacking, and in the hip, complete and full flexion may not be attained. Frequently, except in the hip, there is slight lateral instability, but usually muscle strength is sufficient to compensate for this so that stability is not impaired from a functional standpoint. In the elbow, full restoration of normal motion of flexion and extension is not infrequently obtained, whereas in weight-bearing joints, restoration of normal motion is rarely secured or desired. In the lower extremity, it is desirable to secure about

60 per cent of normal motion since this will give a durable and efficient weight-bearing joint; when motion beyond this range is regained, the muscle power is often inadequate and stability of the joint is impaired. Usually, after a fascial arthroplasty, some degree of crepitus on motion will be present. It is important for both the surgeon and the patient to realize that at best the durability and efficiency of the joint will not equal those of a normal joint.

ROENTGENOGRAMS

The evolutionary process of an arthroplasty is, as would be expected, more apparent in the knee and hip than in the nonweight-bearing joints. In the lower extremity, the joint space tends to become narrow, though in general the articular surfaces are even and smooth. In some knees there may be seen a punched-out area or cavity on the lateral portion of the femoral articular surface corresponding to the normal external condyle, and occasionally similar, though less pronounced, changes may be observed in the tibia. The relations of the articular surfaces will usually remain unchanged unless the integrity of the ligaments is impaired or gross bony irregularities are present. Absorption may also be observed in the hip and elbow, particularly if excessive soft tissue stripping is done at operation. Absorption may to a large extent be obviated by minimizing soft tissue stripping, thus preserving the circulation to the articular end of the bones, and by restricting weight-bearing until the structure of the bone and the strength and endurance of the musculature have been restored.

From a roentgenographic standpoint, the structural changes begin at about the end of the third week after operation when a mottled osteoporosis appears. This will persist until the effect of active use becomes apparent, usually in about three months. After that time, the bony structure is gradually restored to normal as shown by the reappearance of normal bony trabeculae. The structure of the bone, however, may never entirely return to normal because of the effect of the disease on the bone, the long period of immobilization of the joint, and the fact that the function of the joint will never be completely normal. By the end of one to three years, however, the structure should have reached its mature appearance, except for the possible development of degenerative and proliferative changes in later years (Fig. 3). A line of condensation about ⅛ inch in width forms just below the articular surface, with trabeculae running at a right angle to the shaft. This area of increased density corresponds to the subchondral bone plate of a normal joint. During the first year, the area of condensation widens but thereafter remains stationary, this static condition indicating that restoration is completed as far as possible. With the further lapse of time, the bony trabeculae become rearranged according to the new lines of functional stress, the duration of this period of development depending on the co-operation, muscular status, and extent of activity of the patient.

Later, bony proliferation or osteophytic outgrowth from the articular margins is found in about 40 per cent of the cases, while 25 per cent show only slight proliferation, and in the remainder there is none at all. In nonweight-bearing joints, the incidence of marginal bony proliferation is definitely less than in the weight-bearing joints.

In the hip, the vitallium mold tends to obscure the acetabular bony reactions

to some degree and, except by inference, completely obscures the changes in the femoral head which may occur following arthroplasty. Marginal proliferations may be seen about the acetabulum, particularly at its superior border, and to a lesser extent may occur antero-inferiorly in the region of the teardrop. In the atrophic arthritic hip, the acetabulum may become filled with new bone, anchoring the mold in situ to a varying degree. In some instances overgrowth of the edge of the mold occurs. The head of the femur may atrophy, as shown by a shortened distance from the edge of the mold to the trochanters, and after removal of the mold proliferative changes may be noted about the periphery of the head of the femur. It is also conceivable that aseptic sequestrations of the head of the femur may occur, though in our series in which the mold has been removed, this has not been noted.

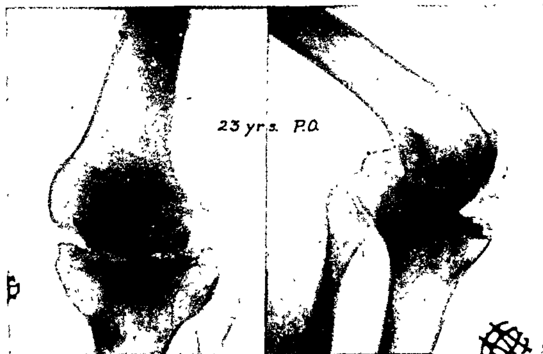


Fig. 3.—Arthroplasty of the knee 23 years after operation. Note the well preserved joint space, and the irregularity of the articular surface of the femur. Motion from 180 degrees to 110 degrees.

Speed and Knight made a rather detailed study of the end-results of fascial arthroplasty of the hip in 225 cases. From a roentgenographic standpoint, it was found that for this particular joint there are certain exceptions to the evolution of a joint, as described above. After the initial period of osteoporosis, the bone constituting the newly formed head and neck will follow one of two courses.

In one group, constituting a relatively large percentage of the cases, osteoporosis will be progressive with gradual absorption of the head and neck despite careful use of graduated exercises and protected weight-bearing. This absorption progresses until at least a portion of the weight-bearing force is shared by the trochanteric surface. In the second group, the general contour and size of the head and neck were found to remain stationary for a period of years, with the

gradual development of changes similar to those seen in the group of osteo-arthritic hips often classified as "secondary osteo-arthritis" following primary pathologic processes as coxa plana, slipped upper femoral epiphysis, traumatic injury of the femoral head followed by aseptic necrosis, etc. There are increased cortical thickening and irregularity of the surface of the femoral head, progressive sclerosis associated with areas of aseptic necrosis, and endosteal proliferation. Occasionally gross infarction or aseptic sequestration of a large portion of the head may be seen. These pathologic changes in varying degree have been observed in all fascial arthroplasties of the hip five years or more old, but occur to a much smaller extent where primary absorption has been a major feature.

Biopsies and Autopsies

From our own series, it has been possible to study seven joints wherein a useful range of motion with function has been regained. In all but one instance the operation was performed because of a mechanical defect, such as instability; in the seventh case, fusion was indicated because of a severe para-articular fracture. Six of the operations were on the knee and one was on the hip. These were performed at periods of 12 months to 15 years after the initial arthroplasty. The findings in these seven joints may be summarized as follows:

The skin and superficial and deep fasciae were normal. The capsule was always found to be thicker than normal, regardless of the lapse of time, but the relative thickness decreased as time went on. The joint cavities were from one-third to one-half the size of those of normal joints, and in some there were fibrous bands traversing the joint. A joint fluid resembling normal synovial fluid was present in 6 of the 7 cases, probably having arisen from the connective tissue spaces of the articular surfaces. In 2 of the cases there were areas of degeneration on the articular surfaces. In those cases studied at the end of a year, the joint cavity was surrounded by a dense fibrous tissue, somewhat resembling the investing fascia lata, but in those joints studied after the lapse of a year, the articular surfaces were covered with a fibrocartilaginous tissue. In one case, where function was so slightly impaired that the indications for a second operation were questionable, the articular surfaces were smooth, but in the remainder, the surfaces showed varying degrees of roughening, even to the extent of furrows, pits, and small bony eminences. These apparently did not interfere with function (Fig. 4).

In no case was true hyaline cartilage found. The tissue structure of the joints restored by arthroplasty corresponds almost exactly to that of a spontaneous arthroplasty, such as a flail pseudarthrosis. There were three fairly well defined layers, a dense fibrous articular layer, beneath which was a stratum of atypical cartilage, and the underlying supporting bone. The superficial fibrous layer was found to range from 50 to 100 micra in thickness; the subchondral bone was, of course, continuous with the underlying bone. The articular surface tissue may arise from either the exposed bone marrow spaces or the fascial graft, if it remains viable. The fibrocartilage arises by metaplasia of the connective tissue of the marrow. The superficial fibrous layer and the stratum of fibrocartilage become more clearly defined as the function in the reconstructed joint is restored.

The superficial fibrous layer is composed of closely packed connective tissue

fibers running parallel to the articular surface with numerous cells which contain flattened nuclei. This layer is continuous with the capsule. In one case, there was evidence of an investment of this capsule by mesothelial tissue, definite villi with several layers of cells being demonstrated. It is possible that this was the remains of the former synovial membrane.

The layer of atypical cartilage lying beneath the superficial fibrous layer must be regarded as metaplastic. In one case, typical cartilage cells, in groups of two or more daughter cells, were observed just beneath the fibrous layer, the remainder of the cartilaginous stratum being composed of many undeveloped cartilage cells and connective tissue fibers. There was no true cartilage matrix, but the fibrous tissue was homogeneous and stained with a basic reaction. If the first layer can be interpreted as an attempt at formation of perichondrium, the remainder of the histologic structure is then seen to be the direct opposite



FIG. 4.—Femoral condyle 10 years after arthroplasty. There is excellent end result despite pitting and irregularity of the articular surface.

of that seen in the normal articular cartilage, i.e., the daughter cells are nearer the articular surface whereas normally the more immature cells are found in the deeper layers nearer the bone. It is possible that in time a normal arrangement of adult cartilage might evolve. Smith-Petersen has presented one case where, on biopsy, normal articular cartilage was found. The finding has not, to our knowledge, been noted in other cases.

The layer of subchondral bone is continuous with the remainder of the bone which enters into the formation of the articulation, the structural restoration by functional adaptation being clearly demonstrated by serial roentgenograms.

The role of the fascial transplant in the formation of the articular surface of bone may be questioned because of the development of a similar fibrous investment in the instance of "spontaneous arthroplasties" and pseudarthroses. From a

practical standpoint, it has been shown that fascia lata does possess a definite action conducive to the development of the joint. The fascia may quite possibly remain viable, since it is in close approximation to the raw bony surface and surrounding soft structures and revascularization from these may readily take place. In time, the structure of the fascia is altered by function. It is indeed doubtful whether an inert soft tissue would withstand the stresses and strains of early function routinely required.

THE USE OF CORTISONE IN ARTHROPLASTY

To say that surgical technic has reached the point of its highest development would be fallacious, but it is quite evident that an increasing proportion of the surgical advances of the future should and will result from the application of the fundamental biologic sciences to surgery, rather than from further development of purely technical surgical procedures alone. Stinchfield has presented one of the most fundamental approaches to the problem in many years in his study on cortisone in conjunction with joint surgery. The study is still in its infancy but nevertheless is of sufficient importance to be presented here. Personal experience with the method in a small series of cases is encouraging.

In searching for a method to prevent excess bone and fibrous tissue formation at or near the site of operation following orthopedic procedures, Stinchfield considered that oxidized cellulose (absorbable gauze), described by Frantz, Clarke, and Lattes, might limit bleeding at the arthroplasty site and decrease the amount of postoperative new bone formation.

He found, in a series of 22 arthroplastic procedures, that bone formation could be inhibited by the use of oxidized cellulose, but that fibrous tissue formation progressed normally or even at an accelerated rate. An experimental study using cortisone was then carried out, since Ragan, Howes, and their associates have shown that wound healing is markedly inhibited by the administration of cortisone. The mechanism by which this is accomplished is not clear, though it appears that the catabolic effect of hyperadrenalism on protein metabolism may account for the decreased activity of the mesenchymal tissues.

From his studies, both experimental and clinical, Stinchfield has found that there is less capsular thickening, more free motion, less crepitation, and a lack of inflammatory reaction when cortisone is used. He feels therefore that cortisone may be employed where inhibition of fibrous tissue formation is to be desired. In treating traumatized joints and in performing arthroplasties, Stinchfield recommends that 100 milligrams of cortisone be injected into the joint at the time of operation, and that similar doses be repeated on the second, fifth, 10th, and 15th days after operation. On the seventh postoperative day, after the skin has healed sufficiently, 100 milligrams of cortisone are given intramuscularly daily for three weeks.

ARTHROPLASTY OF THE KNEE

Ankylosis of the knee, unaccompanied by joint disease elsewhere in the lower extremities, is not a crippling deformity and because of this most orthopedic surgeons agree that a knee which is stiff in a good functional position is to be

fibers running parallel to the articular surface with numerous cells which contain flattened nuclei. This layer is continuous with the capsule. In one case, there was evidence of an investment of this capsule by mesothelial tissue, definite villi with several layers of cells being demonstrated. It is possible that this was the remains of the former synovial membrane.

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According to the position and type of ankylosis present, the technic of operation is modified or varied.

PANANKYLOSIS IN EXTENSION OR SLIGHT FLEXION

It is fortunate that most cases of ankylosis of the knee fall into this category since it is this position of ankylosis which is usually followed by the most satisfactory results. It is not necessary to lengthen the quadriceps tendon as was done earlier in our clinic.

Technic (Campbell). The anteromedial or utility approach of Krida is ordinarily employed, beginning 4 to 6 inches above the knee at the inner margin of the quadriceps tendon, extending distally with a slight convexity medially, parallel with the medial aspect of this tendon, and ending at a point just below the insertion of the patellar tendon into the tibial tubercle. The skin and superficial and deep fascia are incised, and the vastus medialis muscle is dissected from the quadriceps tendon. The tendon is then freed down to the patella, and the bony union between the patella and femur is divided with an osteotome. The quadriceps tendon, patella, and the patellar tendon are then retracted laterally and any obstructing adhesions are freed by sharp dissection. Subperiosteal dissection of the soft tissues from the bone is desirable, but one must avoid leaving small fragments of bone attached to the soft tissues. The ankylosis between the femur and tibia is now divided with a broad osteotome, care being taken to prevent injury to the soft structures posterior to the joint capsule. It is essential to postpone forcible flexion of the knee until the ankylosis is completely divided, even though the ankylosis may be fibrous, since fractures of the distal end of the femur occur with ease and present a serious complication to the success of the procedure.

The knee is gently and gradually flexed, giving complete access to the articular ends of the femur and tibia. The posterior portions of the femoral condyles are removed, obliterating the intercondylar notch and permitting full flexion of the knee with ease. The lower end of the femur is now shaped into one large condyle, convex from above downward and before backward (Fig. 5). Only as much bone is removed from the actual length of the femur as is necessary to reach cancellous bone; relatively more bone is taken from the posterior surface of the condyles, so that a wider space will be obtained with minimal shortening of the bone. The upper end of the tibia is likewise resected only as far as necessary to reach healthy, spongy bone. Using a large gouge, the upper tibial surface is made slightly concave anteroposteriorly, thereby forming a large, single shallow cavity for articulation with the large femoral condyle. After bone excision is completed, it should be possible to produce at least ½ inch of space between the ends of the femur and tibia by manual traction. During the procedure, it is important not to detach the soft tissues from the bone more than necessary, since these carry the chief blood supply of the bone. If excessive denudation of bone is done, aseptic necrosis of the terminal ends of the bones may occur, impairing the end-result.

When remodeling of the ends of the femur and tibia is completed, the bony surfaces are approximated and the alignment of the extremity is inspected. If valgus or varus is present, additional bone is removed from each surface so that

preferred to the uncertainties of arthroplasty. In properly selected cases, however, arthroplasty of the knee offers a practical method of relief from a disabling condition which is a constant source of annoyance and embarrassment, particularly to women. When the procedure is correctly performed, it offers a reasonable expectation of giving the patient 60 to 90 degrees of active movement with adequate muscular control, sufficient stability to allow ordinary activity without the use of external support, and either no pain or pain of such a minor degree as not to interfere with an average day's work in occupations other than those involving manual labor.

Indications

Arthroplasty is indicated in patients with fibrous or bony ankylosis of the knee, who are between 18 and 50 years of age, who do not do manual labor, and in whom the ankylosis is the result of a joint infection or trauma followed by a painful partial ankylosis or by a complete ankylosis wherein the bony components of the joint are not fundamentally disturbed. In earlier years, most arthroplasties were performed for ankylosis resulting from an acute infective arthritis, usually due to gonorrhea or puncture wounds of the joints. More recently, the treatment of acute infections by chemotherapeutic and antibiotic agents has considerably reduced the incidence of ankylosis from these sources.

Contraindications

The procedure is contraindicated when ankylosis is associated with or is incident to generalized atrophic or rheumatoid arthritis, tuberculosis, osteomyelitis, obesity, and osteoporosis. Arthroplasty of the knee may be advised for certain severely disabled patients with multiple ankylosis due to rheumatoid or atrophic arthritis but, in such cases, the purpose of the operation is not the same and the result is ordinarily not as good as in the favorable group.

Mobilization of the ankylosed knee presents a more complex problem than it does in other joints because of the fundamental structure of the knee and the demands made on it in daily use. Stability is of the utmost importance, since without stability motion is of no value. Normally, stability is dependent on ligamentous support on all four sides of the joint as well as within it, on the muscles controlling the joint, and finally on the contour of the articular surfaces. Any mobilizing procedure must result in an intrinsically stable joint as well as one which has a satisfactory range of motion and relative freedom from pain if it is to be considered successful.

It is our experience at the Campbell Clinic that the anatomy of a new knee joint must be simple, making no attempt to restore the normal bony contours of the joint, such as two femoral condyles with an intercondylar notch and two tibial condyles with an intervening tibial spine. Haas has shown that functional adaptation takes place with time and use. This conforms with our findings, and accordingly we attempt to fashion a femoral condyle which corresponds in shape to that which will eventually result from functional use. No attempt is made to form tibial spines or a femoral intercondylar notch, and even though the cruciate ligaments are intact, these are sacrificed at the time of arthroplasty to form the simple monocondylar joint.

bered that it is in the patellofemoral compartment that adhesions first form when reankylosis occurs.

Fascia with which to line the new joint is preferably obtained from the opposite thigh. This minimizes the extent of the operation on the ankylosed leg and makes it possible to remove as much fascia as is needed without disturbing the external support of the operated knee joint. Moreover, in ankylosis due to

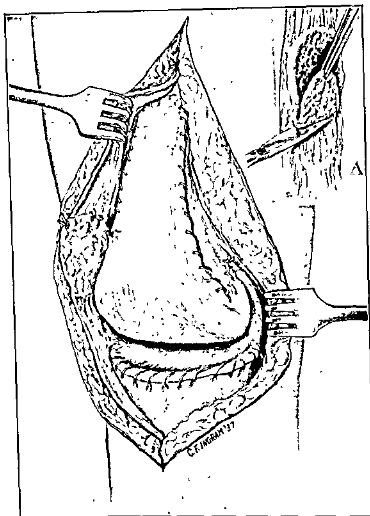


Fig. 6.—Arthroplasty of the knee. The joint cavity is lined with fascia. Note that the fascia is sutured deeply in the posterior compartment of the joint. The insert shows covering of the patella with pedunculated flap of fat and fascia.

(Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics*. C. V. Mosby Co., 1949.)

infection, there may be some fibrosis in the soft tissues about the operative area. A longitudinal, slightly curved incision is made on the outer aspect of the thigh, the subcutaneous tissues are separated from the underlying fascia lata by blunt and gauze dissection, and a sheet of fascia lata 5 inches in width and 8 to 10 inches in length is removed. The insertion of stay sutures in each corner of the sheet of fascia prior to its removal facilitates its handling during insertion into the knee. The rough outer surface of the fascial graft is always placed in contact

a perfectly straight extremity with a hinge joint is formed. Since weight-bearing must be direct and in a straight line, valgus is avoided regardless of the position of the normal limb.

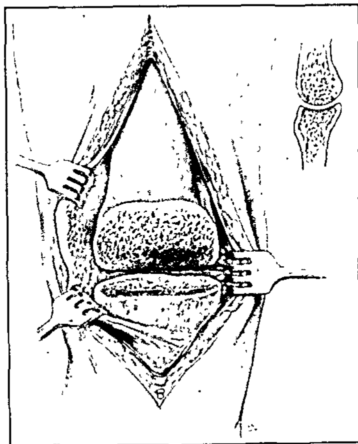


FIG. 5.—Arthroplasty of the knee. Note the formation of monocondylar joint. The patella is remodeled to one half of its normal thickness.

(Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

The patella is now prepared. Its posterior surface is removed, leaving a thin, "wafer-like" patella of good tensile strength. The medial and lateral margins of the patella are resected for ¼ inch in order that the fibers of the tendon along the edges of the patella may be folded onto its posterior surface. All bony surfaces are smoothed with a rasp, and the entire knee compartment is thoroughly inspected in order that all fragments and particles of loose bone may be removed. Campbell advised the use of a pedicled flap of fibrofatty tissue obtained from the infrapatellar fat pad as a covering for the posterior surface of the patella. This is obtained by severing it at its juncture with the tibia and dissecting it upward to form a broad pedicled flap. This flap is then sutured to the margin of the tendinous fibers, thus completely covering the posterior surface of the patella (Fig. 6). In the event that the fat pad is absent or deficient, a free transplant of fascia lata is used to cover the patella, adequate coverage of the patella being a most important factor in restoring mobility of the patella. It must be remem-

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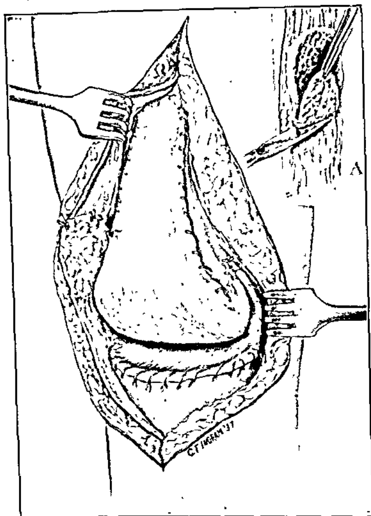


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with the raw bony surfaces. The transplant is folded with its smooth surface inward, two-thirds of its length forming the superior portion. The folded edge is anchored to the upper reaches of the posterior capsule of the knee joint by three interrupted sutures, one placed on each side and one in the center. The upper portion of the transplant is then placed over the femoral condyle and the distal 4 or 5 inches of the anterior aspect of the femur while the lower fold is brought forward over the new articular surface of the tibia to its anterior edge. All free edges of fascia are sutured to the periosteum and soft tissues, well beyond the joint margins. It is preferable to employ continuous sutures of a medium plain catgut to anchor the fascia in place (Fig. 6). If the soft tissues are deficient, the fascia should be anchored by interrupted sutures passed through small holes drilled in the bone or, if the bone is soft, the holes are easily made with a Lewin clamp. Thus two layers of fascia lata are interposed between the joint surfaces and one layer is interposed between the quadriceps tendon and the anterior aspect of the femur. The posterior surface of the patella is covered by the pedicle flap which forms an additional layer of interposing material between the patella and femur.

The use of a tourniquet facilitates the operative procedure, but it must be removed and complete hemostasis secured before insertion of the fascia and closure of the wound. Wound closure is carried out in layers, catgut serving satisfactorily for the deep layers and interrupted nonabsorbable sutures for the skin.

After-care. After operation, the extremity is immobilized in a special arthroplasty splint incorporating moderate traction. This splint is, in effect, a Thomas splint with a Hodgen attachment. The knee is maintained in the extended position, no motion being permitted in the joint until the wound has entirely healed. On the sixth postoperative day, active quadriceps exercises are begun, and on the 10th day, motion may be instituted under the control of the patient and with traction continued. It is desirable that active and passive motion be developed synchronously.

An exception to the above routine is made in obese patients and in the presence of a long-standing ankylosis associated with weak, atrophic muscles, in order to prevent excessive joint laxity. A single spica cast, extending from the toes to above the iliac crests is applied, a large window being removed anteriorly to allow for postoperative swelling. At the end of two weeks, the cast is changed, the new cast extending from high in the groin to the toes, with hinges incorporated at the knee.

Rapid development of motion is not encouraged, the development of motion not to exceed 30 degrees at the end of one month and 40 degrees of motion by the end of two months being considered optimum. Should motion be developed too rapidly, the atrophic ligaments may be overstretched, and the osteoporotic articular surfaces may be compressed, thereby increasing the joint space, causing irregularity of the articular surface, and thus decreasing the stability. In redeveloping muscle power, attention must be paid to the knee flexors as well as extensors. For strength and endurance, complete extension is essential, and a range of flexion of 60 to 90 degrees is to be desired.

If, at the end of six weeks after operation, the joint is stable and muscle power

is good, the splint is removed and walking is allowed in a long leg brace with a control dial at the knee joint to permit a gradual increase of motion. In the presence of excessive osteoporosis, weight-bearing should be partially relieved by the addition of a Thomas ring to the brace. Full weight-bearing is not permitted until the bone structure approaches normal and good power has been developed in the quadriceps. Muscle re-education and strengthening exercises are continued until maximum power is restored.

Panankylosis of the Knee in Acute Flexion

If the flexion deformity of the knee exceeds 60 degrees, a two stage procedure is indicated. In the first stage, the ankylosis is broken up and the deformity is corrected so that weight can be borne in a good functional position. The osteotomy is performed through a posterolateral incision, and if necessary a posterior capsulotomy is done. If there is difficulty in obtaining correction of the deformity, either skin or skeletal traction, in a Thomas-type splint with Hodgen's attachment, is employed postoperatively. As soon as the deformity is corrected, a long leg cast is applied with the knee in extension. After six weeks, weight-bearing is begun in a brace and is continued until the soft tissues and bone are sufficiently normal to permit arthroplasty as described for cases of panankylosis in extension.

Patellofemoral Ankylosis

The persistence of a normal tibiofemoral articulation in the presence of patellofemoral ankylosis is rarely encountered. In such an instance, excision of the patella is preferable to arthroplasty. Usually, in the presence of a patellofemoral ankylosis, there is sufficient disturbance of the femoral and tibial articular surfaces to warrant a complete arthroplasty, as described above. It is the consensus at our clinic that partial and hemiarthroplasties are rarely successful, and that a complete arthroplasty offers a much better outlook.

Tibiofemoral Ankylosis with a Freely Movable Patella

This situation is likewise rarely seen. It may occur as the result of an acute infectious arthritis but it will more often be found to follow a rather severe osteomyelitis with direct extension into the joint. In such cases, the anterior portion of the joint becomes walled off by an inflammatory exudate which protects the patellofemoral compartment from infection, the patella remaining freely movable. The indication for arthroplasty in such a case is questionable, but should the procedure be deemed advisable the patellar tendon is retracted laterally and a routine arthroplastic procedure is carried out, except for omission of treatment of the patella.

End-Results of Arthroplasty of the Knee

One hundred and ninety-four arthroplasties of the knee have been performed in the Campbell Clinic, according to the technic evolved by Campbell. These knees have been found to resist the ravages of time and wear and tear much more satisfactorily than fascial arthroplasties of the hip, both from a functional and roentgenographic standpoint. The hips usually show progressive degenera-

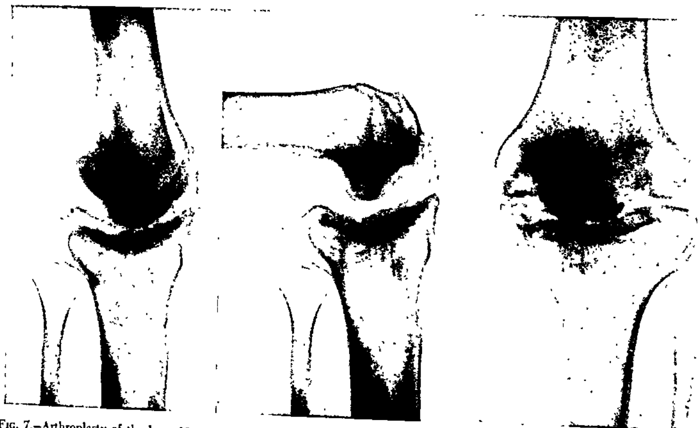


FIG. 7.—Arthroplasty of the knee 11 years after operation. Note the range of motion. Despite irregularity of the joint surfaces there is no instability and activities are not limited by the knee. Excellent end result.

tion, over a period of 10 to 15 years, with bony proliferation. Function decreases, though usually not in proportion to the roentgenographic changes. On the other hand, the degenerative and adaptive changes following arthroplasty of the knee, with few exceptions, are found to become static five to seven years after operation. During the first three years after operation, the joint is in a changing state and does not develop its ultimate degree of motion, stability, or function. After the initial adaptive changes and "settling down" of the joint surfaces, a certain amount of absorption and residual incongruity remains, though this is usually within tolerable limits and is of no real importance. For the next two to three years, muscular control and motion continue to improve so that the knee is found to reach its peak function five to seven years after operation. Thereafter the functional result and the roentgenographic appearance remain stationary for an indefinite period of time (Fig. 7). The eventual functional capacity of the knee joint will depend on the ability of the patient to develop muscle control in order to extend the knee strongly and to stabilize the joint in extension. Many patients with poor function at the end of two years had excellent results at the end of five or six years.

The average arthroplasty of the knee has been found to have motion of 60 to 70 degrees, usually associated with a grating of the patella which becomes painful after excessive use. When the muscles are relaxed and the joint is slightly flexed, there is ordinarily considerable instability, but when the muscles are contracted and the knee is in extension, little instability is present. These patients can walk very well on level ground, having a barely perceptible limp, but may not be able to go up and down steps in a normal manner. Those with greater ranges of motion, may negotiate stairs in a normal manner by raising themselves on the toes of the normal side.

A recent analysis of long-term results made by Speed and Trout has confirmed the above facts. It has shown that a satisfactory knee joint can be reconstructed by arthroplasty and that this joint will withstand ordinary daily use quite well for an indefinite period of time. Two of the most satisfactory results encountered in this study were in patients 22 and 26 years after operation.

ARTHROPLASTY OF THE HIP

Before the development of the vitallium mold arthroplasty of the hip by Smith-Petersen, fascia was universally used as the interposing medium of choice. In general, the results were satisfactory, though absorption and wearing away of the head and neck of the femur were frequent sequelae. The vitallium mold arthroplasty results in a more stable hip, absorption of bone occurs much less frequently and to a lesser degree, the stability of the hip is greater, and, unless the acetabular margins undergo proliferative changes, the range of motion is at least equal to or greater than that resulting from fascial arthroplasties.

Approximately 275 fascial arthroplasties have been performed at the Campbell Clinic, but since 1942 the vitallium cup has supplanted the fascial type of procedure. It is to be emphasized, however, that the Smith-Petersen procedure, although definitely superior to the fascial type, must also be followed by detailed and meticulous postoperative rehabilitation. Until the surgeon has had exten-

sive experience with many cases, the exact technic of the operation and system of after-care as outlined by Smith-Petersen should be followed. Many of the inferior results obtained from this procedure are due to a departure from Smith-Petersen's technic, which has been gradually evolved with an experience dealing with 620 patients and 745 hips.

TECHNIC (SMITH-PETERSEN)

In order to perform the procedure properly according to this technic, adequate exposure of the anterior and medial aspects of the acetabulum, as well as of the medial side of the femoral head, is essential. Exposure of the base of the femoral neck and of the trochanteric region is not ordinarily necessary and is to be avoided if possible. Both joint surfaces are reconstructed to give a congruous and mechanically correct joint.



FIG. 8.—Incision employed in the Smith-Petersen approach to the hip. (Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

The anterior iliofemoral approach is employed, the skin incision beginning at a point on the iliac crest about 3 inches posterior to the anterior superior spine and extending distally along the medial border of the tensor fasciae latae (Fig. 8). The incision terminates at a level approximately 2 inches distal to the lesser trochanter, so that more deeply the distal extent of the approach will be at the level of the motor fibers of the femoral nerve to the rectus femoris muscle. The superficial fat and fascia are incised and the femoral fascia between the sartorius

and tensor fasciae latae is defined. By incising the femoral fascia between these two muscles, a cleavage plane between the posterior surface of the sartorius and the anterior surface of the iliopsoas as it emerges from beneath the inguinal ligament is located and developed by blunt dissection.

The plane of cleavage between the external abdominal oblique muscle medially and the gluteal muscles laterally is located and an incision is made through the deep fascia and periosteum to bone. By subperiosteal dissection, the attachments of the abdominal muscles, sartorius, and inguinal ligament are freed and retracted medially, and the gluteus medius, tensor fasciae latae, and gluteus minimus are freed and retracted laterally, thereby exposing the anterior third of the ilium (Fig. 9).

The origin of the sartorius contains little tendinous tissue and tends to fray, thereby making for a precarious reattachment of the muscle during wound closure. To obviate this difficulty, Smith-Petersen advises that a small portion of the tensor fascia be allowed to remain attached to the proximal end of the sartorius.

The deep iliac fascia is now divided between the main and acetabular origins of the iliacus muscle. The motor fibers of the femoral nerve to the rectus muscle are exposed; they are surrounded by fat and lie on the anterior surface of the iliacus muscle, just beneath the iliac fascia as it merges into the deep femoral fascia.

Attached to the anterior inferior iliac spine, which is now exposed, are the direct head of the rectus femoris muscle and the acetabular origin of the iliacus muscle medially and the reflected head of the rectus femoris laterally, the latter lying concealed in the supra-articular fat compartment. The iliopsoas is retracted medially, exposing the anterior and inferior portions of the hip joint capsule. The sheath of the rectus muscle is preserved and the muscle itself is not dissected out. The rectus muscle and the acetabular origin of the iliacus muscle are divided close to the anterior inferior iliac spine and are reflected laterally with the limbs of the Y-ligament of Bigelow and the capsule (Fig. 10).

The anterior acetabular wall and the inferior half of the anterior inferior iliac spine are now excised, following which the remnants of the fibrous portion of the joint capsule and the synovium are removed, care being taken to protect the distal attachments of the capsule which are the points of entrance of the blood supply to the head and neck of the femur. By this osteotomy, the anterior aspect of the head and neck are exposed and dislocation of the hip can be accomplished with a minimal degree of trauma.

If bony ankylosis is complete and the original joint line is completely obliterated, it will be necessary to fashion a new femoral head before dislocating the hip. For this, special curved gouges having a concavity corresponding to the normal joint curve are used. The new joint line is completely cut through before any attempt is made to dislocate the joint. If the old joint line is not completely obliterated, it will be possible, by the use of a gouge with the same curve as that of the femoral head, to follow the old joint line exactly, changes of pitch emitted by the gouge as it is struck by the mallet guiding the surgeon as to the correctness of the path of the gouge. If the ankylosis is fibrous, the joint surfaces are separated by use of the same gouge.

sive experience with many cases, the exact technic of the operation and system of after-care as outlined by Smith-Petersen should be followed. Many of the inferior results obtained from this procedure are due to a departure from Smith-Petersen's technic, which has been gradually evolved with an experience dealing with 620 patients and 745 hips.

TECHNIC (SMITH-PETERSEN)

In order to perform the procedure properly according to this technic, adequate exposure of the anterior and medial aspects of the acetabulum, as well as of the medial side of the femoral head, is essential. Exposure of the base of the femoral neck and of the trochanteric region is not ordinarily necessary and is to be avoided if possible. Both joint surfaces are reconstructed to give a congruous and mechanically correct joint.



FIG. 8.—Incision employed in the Smith-Petersen approach to the hip. (Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

The anterior iliofemoral approach is employed, the skin incision beginning at a point on the iliac crest about 3 inches posterior to the anterior superior spine and extending distally along the medial border of the tensor fasciae latae (Fig. 8). The incision terminates at a level approximately 2 inches distal to the lesser trochanter, so that more deeply the distal extent of the approach will be at the level of the motor fibers of the femoral nerve to the rectus femoris muscle. The superficial fat and fascia are incised and the femoral fascia between the sartorius

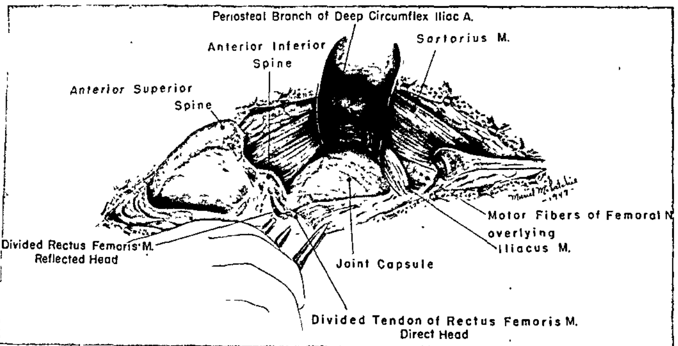


Fig. 10.—The capsule of the hip joint is exposed. The deep fascia between the main and acetabular origins of the iliacus muscle is divided.

(Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

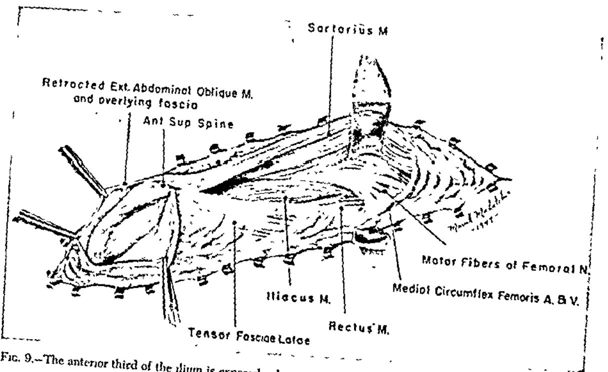


FIG. 9.–The anterior third of the ilium is exposed subperiosteally. The cleavage plane between the sartorius and iliacus muscles is developed.
(Speed, J. S., and Smith, H. [Eds.]. *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

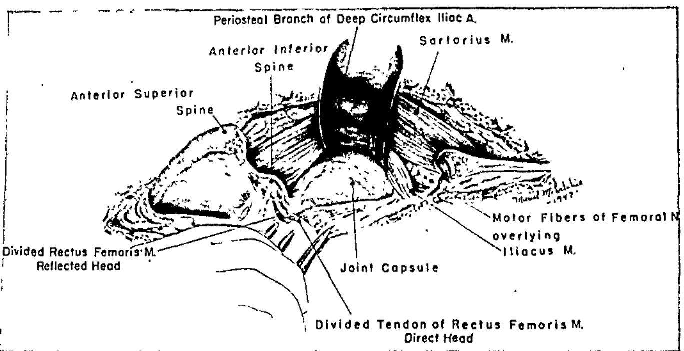


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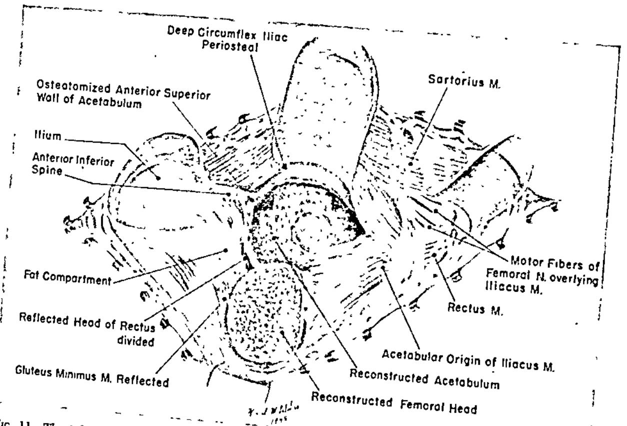


FIG. 11.–The inforior half of the anterior inferior iliac spine and the anterior acetabular wall have been resected. The hip is dislocated and the head of the femur and the acetabulum have been reshaped. (Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

The reconstruction of the femoral head and the acetabulum will depend on the pathology present. In general, the following principles are applicable: The anterior and inferior rims of the acetabulum (the pubic portion of the acetabulum) can be excised without sacrificing stability of the joint. The acetabulum should be deep for stability; posteriorly, the bone excision may be generous. The limbs of the cotyloid notch are always sacrificed and, if necessary, a portion of the iliopectineal eminence may be excised. The semilunar surface of the acetabulum and the floor of the acetabular fossa are removed. When using the ball and cup reamers, care is used to maintain a directional congruity of the joint surfaces so that, for example, a valgus acetabulum and a varus femoral head will not result (Fig. 11). From time to time, as the remodeling of the head progresses, the hip should be reduced in order to be certain that satisfactory bony relationships are being obtained. If the underlying bony process necessitates the formation of a valgus type of hip, the acetabulum must be made unusually deep posteriorly, since in this type of hip flexion and extension take place chiefly between the acetabulum and head. In general, a long neck and a deep acetabulum are preferable, giving a mechanically better hip. A short neck should be associated with a relatively shallow acetabulum, while a varus hip will require the sacrifice of more bone from the depths of the acetabulum. If the short external rotators are contracted, it may be necessary to divide them in order to allow adequate internal rotation of the hip without excessive deepening of the acetabulum. It is desirable to maintain a normal circumferential measurement of the femoral head if practicable. The oversized head should be re-formed in proper anatomic relationship to the neck. Smith-Petersen insists that no cartilage should be allowed to remain on either articular surface, regardless of its condition.

The selection of the proper vitallium mold and its fitting on the head of the femur and in the acetabulum are important parts of the procedure. The mold must not fit snugly on the femoral head or fit so firmly in the acetabulum that it is grasped by the acetabulum. The edge of the mold must extend beyond the margins of the acetabulum in all positions. The mold, on the other hand, should fit the femoral head well enough so that the mold moves with the femur in abduction, adduction, and in part of flexion.

The anterosuperior spine and adjacent crest are excised to facilitate suture of the abdominal muscles and fascia to the gluteal muscles and fascia without tension (Fig. 12). This results in no disability or deformity of the pelvis. The direct head of the rectus muscle is sutured to the reflected head when it has been possible to preserve the latter; otherwise, it is sutured to the central tendon of the gluteus minimus muscle. The deep and superficial fascial layers are approximated by interrupted sutures in layers.

Details of Surgical Treatment in Special Conditions

Malum Coxae Senilis. The problem here is one of deepening the acetabulum, since the usual finding is a shallow acetabulum, located in a relatively lateral plane. The head will require complete remodeling, since it is malshaped, often being "mushroom" in contour, with spur formation at its periphery and with sclerosis of bone and erosion of cartilage. The synovial lining of the capsule,

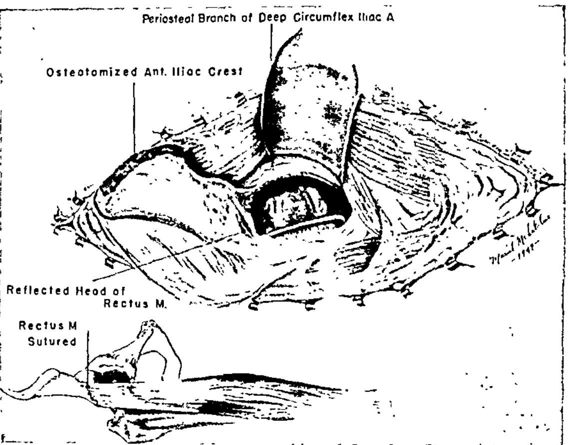


FIG. 12.–The vitallium mold is applied and the hip reduced. The mold fits loosely over the femoral head and in the acetabulum. The anterior iliac crest has been partially resected to allow wound suture without tension. The insert shows suture of the rectus muscle.

(Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

which is usually thickened and villous, is excised. In general, the results are quite satisfactory in this group of cases.

Rheumatoid Arthritis. In this condition, the problem is entirely different from that of the malum coxae senilis type of hip. In addition to ankylosis of varying degree, there is extreme bone atrophy and the muscles are atrophic, fibrotic, and inelastic. Increasing experience in the surgery necessitated by rheumatoid arthritis has convinced Smith-Petersen that it is not necessary to wait until the disease process is entirely quiescent or has "burned itself out" before proceeding with an arthroplasty. Rather, when it becomes evident that an arthroplasty will be required, the procedure should be done as soon as the general condition of the patient can be readied for surgery. Early restoration of motion to the joint will allow the atrophic muscles to resume function and prevent secondary fibrosis. Actually many patients will show general as well as local improvement after such an operation, which allows increased activity and ambulation.

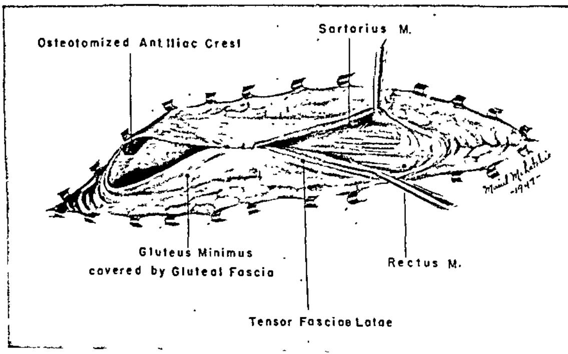


FIG. 13.–Resection of a portion of the anterior iliac crest, including the anterior superior iliac spine, permits wound closure without tension.
(Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

In performing an arthroplasty on this type of hip, wide excision of acetabular bone is carried out and a large vitallium mold is used so that a large metallic surface is in contact with the atrophic bone of the acetabulum. The postoperative treatment (to be described later) is not altered in this type of case despite the presence of bone atrophy.

Both the surgeon and the patient should recognize at the outset in such cases that one or more revisions *may* be necessary. The first mold insertion makes it possible to stretch taut and contracted tissues, to redevelop wasted muscles, and

Fig. 14.—Vitallium mold arthroplasty of the hip for rheumatoid arthritis; excellent function and freedom from pain.



Fig. 15.—Vitallium mold arthroplasty for hypertrophic arthritis. Poor result with limitation of motion and pain due to fixation of the mold in the acetabulum. Note the proliferative cuff of bone extending from the acetabulum over the mold. This patient should have a revision of the arthroplasty.

to construct the elements of a new joint. The purpose of secondary operations is to remodel the joint surfaces and to correct subluxation or faulty relationship of the head, mold, and acetabulum when required.

Revision is indicated in a relatively high percentage of cases of mold arthroplasty done for this condition. Quite often revision will result in marked improvement in function and decrease in pain. Usually, in addition to removal of bony spurs and ledges from the acetabular margin and even from the neck of the femur at the periphery of the mold, remodeling of the acetabulum is necessary in order to change its plane and to make it more roomy; this is followed by insertion of a larger mold. If a change in the relationship of the mold to the head is indicated, remodeling of the femoral head itself will be necessary.

The role of cortisone in obtaining a remission so that an arthroplasty can be done, and in preventing postoperative fibrosis and new bone production is not yet established. Limited experience at the present, however, indicates that it may have a most favorable influence on these surgical problems as well as in preventing the progress of the disease.

Complications of Fractures of the Neck of the Femur. Where union of the fracture has been obtained but an aseptic necrosis of the femoral head has followed, a routine arthroplasty may be performed as described for cases of malum coxae senilis, providing the aseptic necrosis is of a relatively slight degree. If the necrotic area is more extensive, the area of necrosis is excised down to viable, bleeding bone and the defect is filled with cancellous bone obtained from the iliac crest. Smith-Petersen terms this the "rosebud" procedure and advises that the defect be packed sufficiently to allow the grafts to protrude slightly above the surface of the femoral head itself. This modification can be successfully employed even where the sequestral defects are large. If the femoral head cannot be salvaged, a modification of the Whitman procedure is indicated, employing a vitallium mold and transplanting the greater trochanter distally.

Where there is a nonunion of the fracture with an aseptic necrosis of the femoral head, modifications of the mold arthroplasty are indicated. If sufficient femoral neck remains, the greater trochanter is transplanted distally on the femoral shaft and a modified Whitman reconstructive procedure is performed, using a vitallium mold. Where the neck of the femur has undergone complete resorption, a modification of the Colonna operation is a more satisfactory procedure, the greater trochanter being transplanted into the acetabulum and covered by a mold. Such a procedure often results in relative instability and weakness of the hip so that the insertion of the abductor muscles must be displaced downward and the acetabular roof extended laterally by means of a vertical osteotomy of the roof. The defect is filled with cancellous grafts obtained from the crest of the ilium.

After-care

The extremity is suspended in a modified Thomas splint, using 5 to 8 pounds of traction and maintaining the hip in 20 degrees of abduction and in a position of neutral or slight internal rotation. The splint slings are purposely made deep in order to control external rotation. In the exceptional case, a plaster slab may be placed along the lateral aspect of the trunk and extremity in order to prevent adduction. Traction is continued ordinarily for four weeks, except in elderly

Fig. 14.—Vitallium mold arthroplasty of the hip for rheumatoid arthritis; excellent function and freedom from pain.

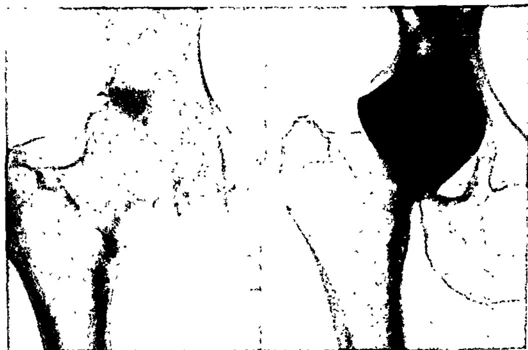


Fig. 15.—*Vitallium mold arthroplasty for hypertrophic arthritis. Poor result with limitation of* motion and pain due to fixation of the mold in the acetabulum. Note the proliferative cuff of bone extending from the acetabulum over the mold. This patient should have a revision of the arthroplasty.

patients and in those cases where an arthroplasty of the opposite hip is to be performed during the same hospital admission.

Muscle-setting exercises and gentle active motion are begun the day following operation and are increased as tolerated by the patient. The muscle exercises include quadriceps muscle development, internal rotation exercises of the hip, and exercises for the muscles of the foot and ankle. The patient may be allowed partial back-rest privileges for short periods of time, but these are discontinued if any evidence of hip flexion contracture appears.

Roller skating on the polished board is begun late in the fourth or early in the fifth week, the hip being maintained in a position of neutral rotation. Active abduction is encouraged with progressive resistance in abduction afforded by controlled pulley and weight resistance and by elevation of the outer end of the board.

The patient is usually allowed out of bed in the fourth week, though occasionally it may not be permitted until the sixth week. First, he is allowed to sit a few minutes in a firm, high armchair, being assisted from the bed to the chair by two attendants. While sitting, he should perform exercises for dorsiflexion and plantar flexion of the ankle as well as for internal rotation of the hip. Positional external rotation is to be avoided.

Exercise on the stationary bicycle is begun before walking. This form of exercise provides active and passive strengthening of the hip flexors and extensors as well as stretching exercises in flexion. The seat may be lowered or raised as indicated to increase flexion or extension. Toe straps should be used to fix the feet to the pedals so that the patient can pedal backward; by pulling up against the pedal, strengthening exercise for the iliopsoas is obtained. In the event that the patient *is unable to go through a complete revolution of the pedals, bicycling* with a seesaw motion is beneficial. Smith-Petersen also recommends that the patient rock in a rocking chair, as this has an effect similar to that of bicycling. It should be stressed that exercises should not be carried out to the point of excessive fatigue.

The patient is ordinarily allowed to begin walking in the fifth week. Initially, this is done with the assistance of the surgeon and only partial weight-bearing on the affected extremity is permitted. When he obtains sufficient balance and stamina, the patient is taught to walk in a mechanical walker. Crutches are not employed until the patient can adequately control the extremity and has sufficient strength to walk with confidence. Walking with crutches is generally continued for six months, the patient being checked periodically to ascertain that his crutch gait is correct.

After discharge from the hospital, usually six to *eight weeks after operation* in the unilateral case and eight to 10 weeks in the bilateral case, the patient must report for periodic check-ups. He is placed on a specific routine of rest and exercise, including bicycling, roller skating exercises, walking, and rocking in a rocking chair. Stretching exercises are given, particularly to increase the range of motion and to strengthen the power of abduction, internal rotation, and flexion and extension of the hip. Gentle stretching in flexion, extension, abduction, and internal rotation is done two to three times daily in order to increase the range of motion and build up the patient's strength and endurance.

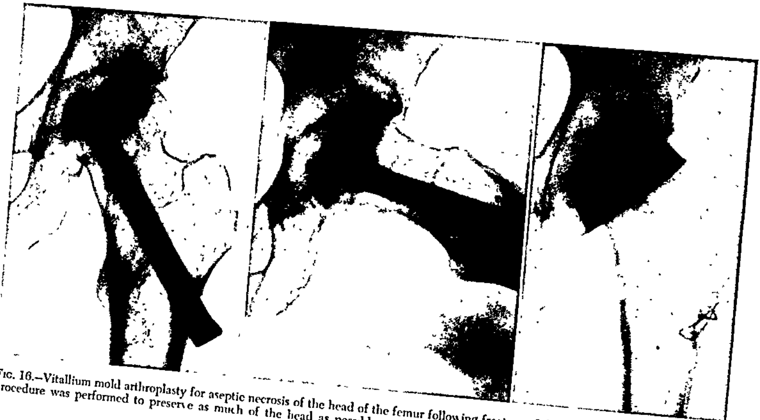


Fig. 16.—Vitallium mold arthroplasty for aseptic necrosis of the head of the femur following fracture of the neck of the femur. "Rosebud" procedure was performed to preserve as much of the head as possible, and trochanteric muscles were transferred. Excellent result.

pression, however, of those who have used the procedure is that in properly selected cases it is a satisfactory method. It is adapted to cases of malum coxae senilis, residual stages of deformity of slipped femoral epiphysis, and coxa plana, and the approach may be used in preference to the posterior gluteal splitting procedure for open reduction and internal fixation of posterior fracture-dislocations of the hip.

Technic (*Gibson*). The patient is placed in the lateral position, kidney supports, a hip "trough," or properly placed and anchored anterior and posterior sandbags being used to maintain him in this position during the operation. The

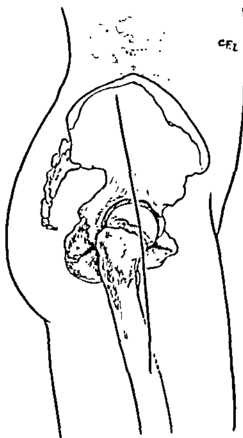


Fig. 17.—Posterior approach to the hip (Gibson). The skin incision is shown in relation to the bony landmarks.
(After Gibson, A: *J. Bone & Joint Surg.*, *32B*:183, 1950.)

incision begins at a point just below the crest of the ilium, overlying the interval between the gluteus maximus and medius muscles, and extends downward to the upper anterior border of the greater trochanter and thence distally along the line of the femur for 6 inches (Fig. 17). The skin and subcutaneous fat are incised down to the fascia and the flaps are reflected a short distance anteriorly and posteriorly by blunt dissection. The iliotibial band is incised at the distal end of the wound, the incision extending proximally in line with its fibers. In the region of the greater trochanter, the gloved finger is inserted in the proximal end of the incised iliotibial band and the sulcus at the anterior border of the gluteus

The patient who has had a mold arthroplasty must be made to understand thoroughly that a prolonged period of follow-up is necessary, since an end-result cannot be said to have been reached even after 10 years. At first, the complaints of the patient may be referable to a faulty gait or overuse, while later structural changes, such as bony proliferations at the periphery of the joint, excessive deepening of the acetabulum, or locking of the mold within the acetabulum, may be the cause of increasing pain or limitation of motion. All complaints must be carefully evaluated and should revision of the arthroplasty be indicated, the surgeon should do it without hesitation since such revisions often result in greatly increased function and decreased pain.

Follow-up Study (Law)

Law, in a thorough study of 150 cases of vitallium mold arthroplasty performed by Smith-Petersen, found 80 per cent of the late results satisfactory to both patient and surgeon. The results varied somewhat with the underlying condition necessitating operation, and, in general, the best results were obtained in cases of traumatic arthritis and malum coxae senilis, while the poorest results were found among patients with rheumatoid arthritis. In the latter group, however, the results more than justified the procedure in that bedridden patients were enabled to walk with crutches, sit comfortably, and often to earn a living.

The majority of these patients found a cane necessary for distance walking. The average range of flexion movement was 70 degrees during the first two postoperative years, 75 degrees during the next two years, and from four to six years postoperatively the average range of flexion was 80 degrees. In general, hip movement was smooth and free from pain, permitting an elastic and well balanced gait. Law stresses the importance of a carefully supervised program of exercise and gait re-education during the first two years after operation.

Late avascular necrosis and absorption of the femoral head and neck, so frequently found in fascial arthroplasties of the hip, were rare. This, Law feels, is due to the routine remodeling of the femoral head down to bleeding cancellous bone. It would seem, however, that the vitallium mold plays an important role in preventing such complications. At the Campbell Clinic, it has been routine to remodel the femoral head sufficiently to expose bleeding cancellous bone, but in spite of this precaution, absorption occurred frequently following fascial arthroplasty of the hip.

The Gibson Modification of Smith-Petersen's Vitallium Mold Technic

In 1948, Alexander Gibson of Winnipeg presented a modification of Smith-Petersen's mold arthroplasty which is particularly applicable to cases of hip joint disease wherein the acetabulum remains relatively normal. This operation is performed through a modification of the Kocher-Langenbeck approach, one discarded and long forgotten by the vast majority of orthopedic surgeons on this continent. The approach is simple, extensible, and almost bloodless, and because it is unnecessary to detach the gluteal muscles from the ilium or interfere with the function of the iliotibial band, postoperative rehabilitation is prompt. Since the end-results have not been reported from any large series of cases, no final evaluation of the procedure can be given. The preliminary im-

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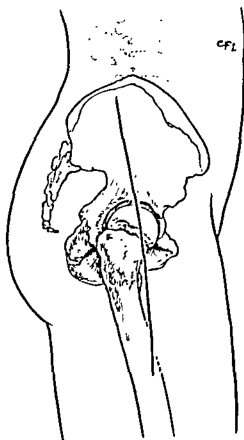


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intertrochanteric line; as much of the capsule as desired may be incised along the joint line anteriorly and the anterior intertrochanteric line laterally. If an osteophytic cuff is present along the acetabular margin, this is removed with an osteotome to facilitate dislocation of the hip. The hip is now easily dislocated by flexing the hip and knee and adducting and externally rotating the thigh.

The acetabulum is carefully inspected for loose fragments of bone and for surface irregularity. If the acetabulum is smooth, it is not disturbed, even though areas of erosion and eburnation may be present. Adequate excision of any bony outgrowth of the rim of the acetabulum is now completed and attention is turned to the femoral head.

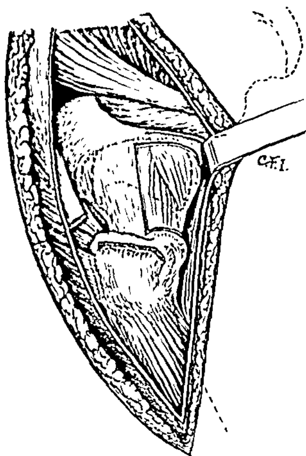


Fig. 19.—*Posterior approach to the hip (Gibson). The short muscles are detached from the greater trochanter and retracted, exposing the capsule. The capsular incision is shown.* (After Gibson, A., *J. Bone & Joint Surg.*, 32B:183, 1950.)

The femoral head is remodeled with an osteotome, its globular shape being maintained. Any marginal osteophytes are removed, the soft tissues of the neck of the femur being protected as completely as possible in order to preserve the circulation of the head of the femur. A cup reamer is used to complete the re-shaping of the femoral head (Fig. 20).

A vitallium mold is now selected which will move smoothly and easily in the acetabulum as well as on the head of the femur. The hip is now reduced by in-

maximus muscle is palpated. The incision is then extended upward in this interval. The anterior and posterior masses are then reflected, exposing the greater trochanter and the muscles inserted into it, namely, the gluteus medius, gluteus minimus, piriformis, obturator internus, gemelli, obturator externus, and quadratus femoris (Figure 18). During this dissection a minimal amount of bleeding is encountered.

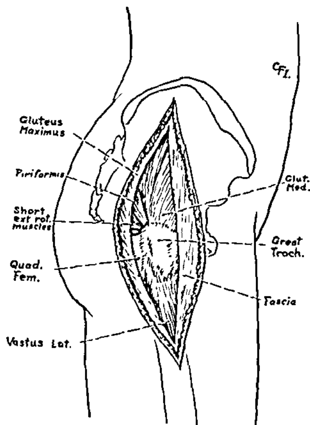


FIG. 18.—Posterior approach to the hip (Gibson). The fascia lata and the gluteal fascia are incised. The gluteus maximus with aponeurotic prolongation is retracted. The muscles attaching to the greater trochanter are exposed.
(After Gibson, A.: *J. Bone & Joint Surg.*, *32B*:183, 1950.)

The posterior border of the gluteus medius is then defined and the muscle is separated from the adjacent piriformis tendon by blunt dissection. The gluteus medius and minimus muscles are incised at their insertion into the greater trochanter, sufficient portions of the tendons of insertion being left attached to the greater trochanter to permit easy approximation during closure of the wound. Both of these muscles are reflected forward. The tendon of insertion of the piriformis muscle is defined and divided. If necessary, the short external rotators may be separated at their insertion, but it is rarely necessary to detach the quadratus femoris from the femur (Fig. 19).

The joint capsule, now visualized in its anterior and superior portions, is incised superiorly in line with the neck of the femur, from the acetabulum to the

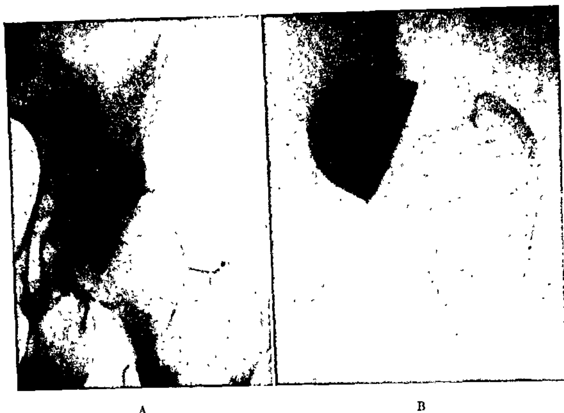


Fig. 21.—Vitallium mold arthroplasty, Gibson modification. (A) Preoperative appearance. (B) Postoperative appearance. Note removal of the acetabular spurs, but the acetabulum is not otherwise disturbed.

TEMPOROMANDIBULAR ARTHROPLASTY

Arthroplasty of the temporomandibular joint is the one mobilizing procedure which has virtually no contraindications, since the disability is distressing and embarrassing as well as one which interferes with eating and oral hygiene. The first report of an excision of the condyle of the mandible for relief of ankylosis of the jaw is that of Humphrey, published in 1856. Bottini is said to have approached the temporomandibular joint through a vertical incision in front of the ear in 1872. In 1880, Robert Abbé of New York employed an approach to the joint through a right-angled incision, the vertical limb lying just in front of the ear and the horizontal limb extending along the lower border of the zygomatic arch. The various interposing membranes have been tried and discarded in favor of simple bone resection, which requires less time, a smaller exposure, and is an easier and less hazardous procedure. It is just as effective as fascial arthroplasty, provided sufficient bone is excised and the raw bone ends are kept separated until the muscles have regained their function.

The procedure is indicated in fibrous and bony ankylosis of one or both temporomandibular joints and in cases of internal derangement, including recurrent forward dislocation. The majority of cases of ankylosis are the result of infection, either hematogenous in origin or from local extension of an adjacent aural infection. Ankylosis of long standing will result in underdevelopment of

ternally rotating and abducting the thigh and extending the hip. Gibson advises resuture of the flap of capsule, but in many instances excision of the capsule is necessary because of synovial involvement. The gluteus medius and minimus muscles are allowed to fall back into position and are sutured to their tendons of insertion with interrupted sutures. The piriformis is next approximated. If division of other short hip muscles has been necessary, these are also resutured. The gluteus maximus muscle and fascia lata are approximated with a continuous suture.

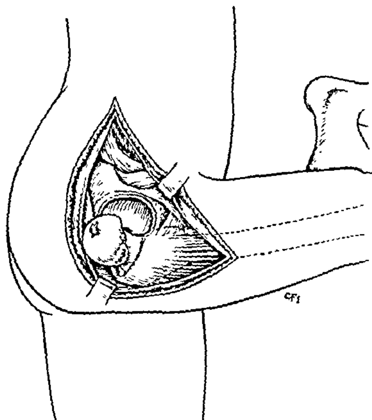


Fig. 20.—Posterior approach to the hip (Gibson). The hip is dislocated. Note the exposure of the femoral head and acetabulum afforded by this approach.
(After Gibson, A · *J. Bone & Joint Surg*, 32B.183, 1950.)

Downward transplantation of the greater trochanter is easily performed when necessary. If the necessity of this is recognized prior to operation, the greater trochanter may be separated with a Gigli saw or osteotome, preserving the bony attachment of the short rotator muscles. During closure, the vastus lateralis muscle is split and the trochanter anchored distally, the fascia of the trochanteric muscles being imbricated with the fascia of the vastus lateralis, so that not only is the trochanter itself displaced distally, but the muscle mass of the two groups is blended.

TECHNIC (CAMPBELL)

A horizontal incision is made, beginning at a point ½ inch in front of the external auditory canal and extending forward along the lower border of the zygomatic arch for a distance of 1 inch. Dissection is carried down to the zygoma and thence down to the temporomandibular joint. If greater exposure is necessary, the incision is extended either upward or downward in front of the ear at a right angle to the first incision. Posteriorly, the superficial temporal artery and vein ascend just in front of the tragus, accompanied by the auriculotemporal nerve, while anteriorly, the temporal branches of the facial nerve must be avoided.

The upper ¾ inch of the condyloid process of the mandible and the inferior and lateral surface of the zygomatic arch are exposed subperiosteally. The condyloid process is then divided with a sharp osteotome at a point about ½ inch below its articular surface. If the ankylosis is fibrous, the condyle is removed by

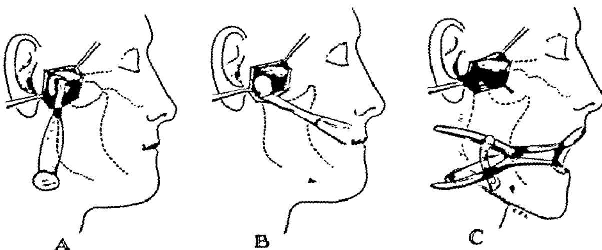


FIG. 22.—Arthroplasty of the temporomandibular joint. (A) The joint is exposed and ankylosis is broken up. (B) Resection of ½ inch of the condyloid process. (C) Joint surfaced re-formed. No fascial interposition is necessary.

(Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics.* C. V. Mosby Co., 1949.)

sharp dissection, care being taken not to injure the internal maxillary or internal pterygoid arteries which lie just medial to the joint. If the joint ankylosis is bony, it is now severed by means of an osteotome. Should one encounter difficulty in removing the excised segment of bone, force should not be employed. In such cases, there may be a solid fusion between the mandibular condyle, the base of the skull, and the anterior aspect of the middle ear. Forcible extraction of the condyle by powerful levering and twisting can then result in a fracture through the base of the skull or through the tympanic portion of the temporal bone into the middle ear. When such a condition is encountered, it is safer to forego extraction of the condyle and to resect a large segment of the ramus further down.

After removal of the condyle, the upper end of the condyloid process is rounded to form a convex articular surface and the mandibular fossa is made concave with a small curved gouge. Interposition of tissue between the resected surfaces is not necessary (Fig. 22). The wound is drained for 24 hours after operation.

the jaw in a growing person, the deformity being either asymmetric or symmetric, depending on whether the affection is unilateral or bilateral. Malocclusion then follows, with the lower jaw receding. When the ankylosis, either unilateral or bilateral, has persisted for a long period of time, the muscles of mastication will undergo atrophy of disuse, fibrotic changes, and structural contracture. In cases of Strümpell-Marie arthritis in adults, the muscles may never recover their normal contractility, but the ability to open the mouth even for a distance of ½ inch is of great importance to these patients. In adults, it is frequently necessary to operate on both joints in case of a unilateral ankylosis of long-standing since the opposite joint may have become secondarily stiffened.

Before operating on a patient with this condition, the surgeon should determine whether the affection is unilateral or bilateral, what type of ankylosis is present, and what the condition of the muscles of mastication is. Ordinarily, the internal pterygoid and masseter muscles suffer only from an atrophy of disuse and will regain a reasonable degree of function, while the platysma, in the absence of stronger depressors of the mandible, will serve such a function.

It is not unusual for the examiner to have difficulty in determining which of the two temporomandibular joints is ankylosed. Generally, however, there will be some slight motion or "give" noted in the mobile joint, despite solid bony ankylosis of the other joint. The chin ordinarily moves toward the affected side. The affected side is, as a rule, somewhat smaller and the facial muscles are flatter and smaller than on the unaffected side. In many cases a helpful history can be obtained or telltale scars may be found. Differentiation must also be made between the extra-articular and intra-articular types of ankylosis. The extra-articular type, ordinarily due to cicatricial contractures of either the cheek or buccal surface, is treated by plastic replacement of the scarred tissue with pliable flaps which will then release the mandible.

The question of anesthesia is an important problem in these cases, since obstruction of the airway during the course of operation becomes a critical emergency. Consequently, a tracheotomy set should be constantly available both during the operation and during the period of convalescence until the patient regains satisfactory control of his jaw. In adults, local anesthesia is quite satisfactory, but in children a general anesthetic is necessary and ample provision for a patent airway must be made by the anesthetist.

A review of results obtained by this procedure at the Campbell Clinic has revealed that recurrence of ankylosis takes place quite frequently in cases of postinfective bony ankylosis in children when the usual condylar resection is performed. In ankylosis resulting from rheumatoid arthritis and the variant, Strumpell-Marie arthritis, the results have likewise been disappointing. Kelikian has recently presented a method of mobilizing this joint through a superior approach which permits a more complete resection of the temporomandibular area without endangering the upper branches of the facial nerve to the frontalis muscle. This procedure will be found most useful for cases of solid bony ankylosis and for cases in which reankylosis has occurred because of a progression of the arthritic condition. On the other hand, the conventional condylar resection is quite satisfactory for cases of fibrous ankylosis and for internal derangement of the joint necessitating resection.

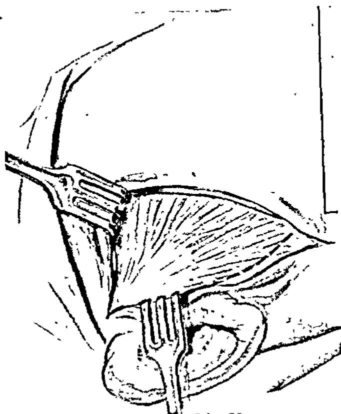


Fig. 23B.—Anthroplasty of the temporomandibular joint (Kelikian). The incision is developed through the temporal fascia and muscle to the skull.
(Kelikian, H.: *J. Bone & Joint Surg.*, 32A:113, 1950.)

ing forceps placed beneath it. The fascia divides into two layers as it nears the zygomatic arch and between these layers lies the small middle temporal artery. The temporal muscle is split and the larger anterior portion is reflected forward by subperiosteal dissection, the muscle carrying forward with it and protecting the superficial temporal vessels and the temporal branches of the facial nerve (Fig. 23B). If more room is needed distally, it will be necessary to ligate and divide the small anterior auricular artery which branches posteriorly from the superficial temporal artery.

The superficial temporal muscle is now followed down to its insertion into the coronoid process, and the zygomatic arch is divested of its temporal fascial attachments by subperiosteal dissection in a forward direction. The articular eminence of the temporal bone is next exposed. The lateral and inferior surfaces of the articular tubercle and zygomatic arch are cleared subperiosteally, and the temporomandibular ligament and joint capsule are excised (Fig. 24A). The posterior root of the zygomatic arch is now severed from the temporal bone by means of a sharp osteotome placed flush with the outer surface of the squamous portion of the temporal bone. The lateral portion of the roof of the temporomandibular joint and the articular tubercle are excised and the zygomatic process is divided with bone-biting forceps at the posterior edge of the masseter muscle. The

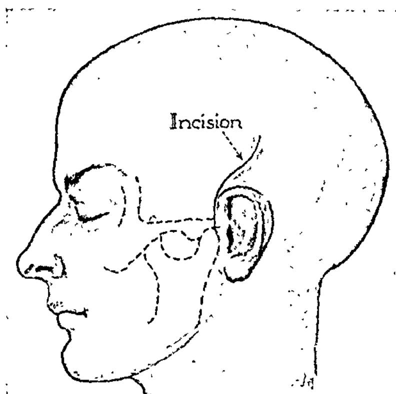


Fig. 23A.—Arthroplasty of the temporomandibular joint (Kelikian). Skin incision. (Kelikian, H.: *J. Bone & Joint Surg.*, 32A:113, 1950.)

After-care. As soon as pain and tenderness subside, active motion is instituted, usually within a few days after operation. The patient is initially placed on a liquid diet which is increased to more solid foods as rapidly as possible and he is encouraged to chew gum as a form of exercise. Physical therapy is not ordinarily required, since the patient can satisfactorily regain the jaw function with little difficulty. If secondary soft tissue contracture is present, opening of the mouth is gradually increased by the use of a cone-shaped obturator, a mouth gag, or an increasing number of tongue depressors placed between the teeth. The latter serves quite satisfactorily in children, since the gradual increase in the number of tongue depressors placed between the teeth can become a game. Passive stretching of the mouth opening should be continued for a period of at least six months in children and in cases where reankylosis is prone to occur.

When the mouth can be opened sufficiently, the patient should consult a dentist so that any necessary dental repair or treatment can be instituted. Appropriate measures to restore occlusion may be instituted at this time.

Technic (Kelikian)

The incision begins at a point 1½ inches above the ear and curves downward, backward, and then anteriorly, descending in front of the ear but behind the superficial temporal artery to the level of the tragus (Fig. 23A). The temporal fascia is split from the upper to the lower end of the incision, guided by spread-

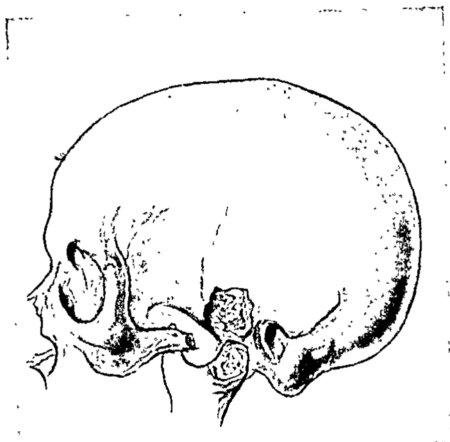


FIG. 24B.—Arthroplasty of the temporomandibular joint (Kelikian). Extent of resection required to expose the ankylosed joint.
(Kelikian, H.: *J. Bone & Joint Surg.*, 32A:113, 1950.)

disturbed, but the bony projection extending downward from it medially is excised. All bone chips are now removed, raw bone surfaces are smoothed, and the concavity created is packed with oxycel gauze (Fig. 25A). The temporal fascia and skin are then closed over the oxycel pack without drainage (Fig. 25B).

If the condition is bilateral, the second operation is performed two to three weeks following the first procedure.

After-care. Skeletal traction (Fig. 26) is routinely employed, being applied immediately after operation in the unilateral case and at the completion of the second operation in the bilateral case. Traction keeps the raw bony surfaces separated, pulls the chin forward, and maintains it in position until healing occurs, and exerts resistance against which the unused muscles of mastication can function. The Kirschner wire is inserted transversely through the point of the chin, a small traction loop being applied. The adult with a normal cervical spine and normal muscles can tolerate 10 to 13 pounds of traction, while in children, 3 to 4 pounds will be sufficient. This is continued as long as tolerated, usually at least five weeks. When the patient is allowed up, the weight is reduced while the force of gravity is effective. In the case of the arthritic patient with involvement of the cervical vertebrae, countertraction, consisting either of Crutchfield tongs or the Minerva type of plaster jacket, is employed (Fig. 26).

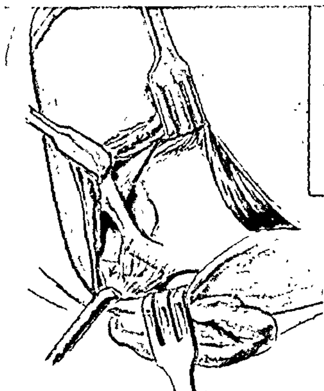


FIG 24A.—Arthroplasty of the temporomandibular joint (Kelikian). The temporal muscle is retracted forward and the zygoma and temporomandibular region are exposed subperiosteally. The dotted line indicates the capsular incision.
(Kelikian, H.: *J. Bone & Joint Surg.*, 32A:113, 1950.)

articular condyle is now visualized and the exact nature and extent of the temporomandibular ankylosis are determined (Fig. 24B).

The upper portion of the ramus of the mandible with its coronoid and condylar processes is freed subperiosteally from above downward. Special care must be used in the dissection posterior to the condyloid process and ramus so that the external auditory canal and the tongue of parotid gland which lies between the meatus and the condyle are not inadvertently injured. Kelikian prefers the use of an electric burr with an acorn tip to bore several holes through the outer plate of the condyle or ramus, connecting these burr holes with a rongeur or bone-biting forceps. After the inner cortex is cut, a curved periosteal elevator is inserted from above downward inside the ramus to protect the internal maxillary artery which passes just medial to the bone. The jaw is then pushed up over the periosteal elevator and the proximal portion of the ramus of the mandible and its processes are removed bit by bit with a rongeur until a joint space of at least ¾ inch is created.

If there is bony fusion between the ramus anteriorly and the petrous or tympanic portion of the temporal bone posteriorly, more bone is excised from the posterior aspect of the ramus, while in congenital synostosis it is necessary to resect more bone from the anterior border of the ramus. The articular fossa is not

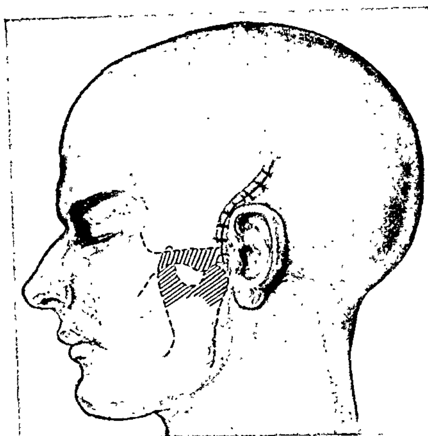


Fig. 25B.–Arthroplasty of temporomandibular joint. Wound closure; the shaded area demonstrates the extent of the bone resection.
(Kelikian, H.: *J. Bone & Joint Surg.*, 32A:113, 1950.)

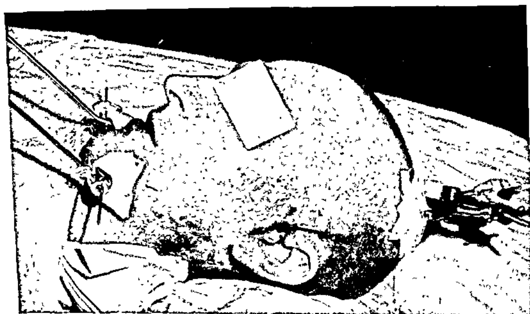


Fig. 26.–Arthroplasty of the temporomandibular joint (Kelikian). Postoperative traction: Kirschner wire is inserted transversely through the chin. Countertraction by means of Crutchfield tongs.
(Kelikian, H.: *J. Bone & Joint Surg.*, 32A:113, 1950.)

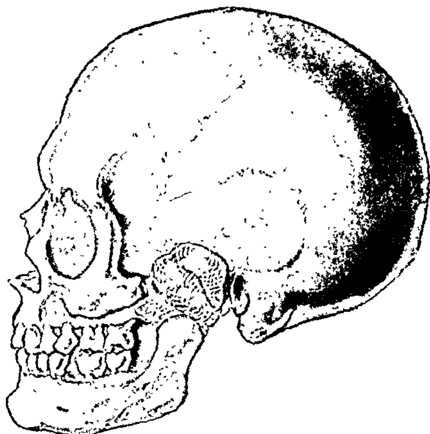


FIG. 25A.—Arthroplasty of temporomandibular joint (Kelikian). The new joint space is packed with oxycel gauze.
(Kelikian, H., *J Bone & Joint Surg.*, 32A:113, 1950.)

ARTHROPLASTY OF THE ELBOW

As in the temporomandibular joint, the contraindications for arthroplasty of the elbow joint are few as compared with those for arthroplasty of weight-bearing joints. In general, it can be said that the following are the only contraindications of consequence: tuberculosis, ankylosis of one elbow in a laborer or other person who requires a strong stable elbow, and cases where there are extensive scarring and damage to the adjacent and overlying soft tissues. Trauma is responsible for ankylosis more frequently in the elbow joint than in any other, primarily because of the complicated structure of the joint itself and the relative lack of tolerance of the joint for mechanical incongruity.

A study of the end-results of arthroplasty of the elbow performed at the Campbell Clinic revealed that, with few exceptions, the patients were benefited by the operation, even though the joints almost universally showed some degree of weakness and some instability; this is usually not sufficient to interfere with

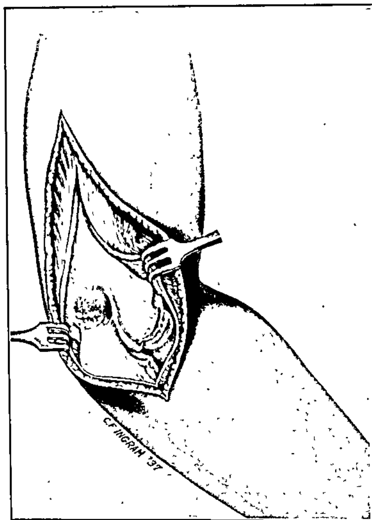


FIG. 27.—Arthroplasty of the elbow. This method of joint exposure is employed where lengthening of the triceps is not required.
(Speed, J. S. and Smith, H. [Eds.]: *Campbell's Operative Orthopedics*. C. V. Mosby Co., 1949.)

ulna, the radial head is excised at the level of the radial neck, but if the superior radio-ulnar articulation remains intact, resection need not be quite so extensive. The edges of the three bones making up the articulation are smoothed with a small sharp osteotome and a rasp, all bony debris is removed, and the wound is flushed with saline. The tourniquet is now removed and hemostasis is obtained.

A sheet of fascia lata of sufficient size to cover the remodeled joint is removed from the lateral aspect of the thigh. The fascial graft is folded in half, the rough surface being placed on the outer side so that it will lie in apposition with bone. The folded edge of the fascia is then anchored to the anterior joint capsule with three catgut sutures, one suture on each side and one in the center. The upper portion of the transplant is reflected over the condyles of the humerus, the lateral edges of the transplant being sutured to the adjacent soft tissues and to the bone itself (Fig. 28). If the soft tissues are insufficient for firm anchorage of the fascia,

ordinary activities. Pain occurs rather infrequently and usually after excessive use. Instability is the result of bony absorption, particularly of the lower end of the humerus, which occurs in the first few years following operation. The cause of this absorption is not known, though it is felt that excess stripping of the soft tissue attachments of the articular ends of the bone at operation is largely responsible. For this reason, excessive soft tissue denudation of bone at the time of operation is to be avoided.

Flexion and extension can be restored to a practical degree, this range usually being from 45 degrees of flexion to 150 to 165 degrees of extension. Attempts to restore pronation and supination have been less successful in our hands. MacAusland makes no attempt to restore motion in rotation because of the possibility of creating an unstable weak joint if this is done.

TECHNIC

The posterolateral incision is considered quite satisfactory for arthroplasty of the elbow. We have not found it necessary to use more than one incision or an approach in which either the olecranon is divided or the internal epicondyle severed. The incision begins at a point 4 inches above the elbow on the posterior surface of the arm, just lateral to the midline, and extends distally to a point 3 inches below the tip of the olecranon. The deep fascia is incised and the soft structures are elevated medially 1 inch, exposing the triceps aponeurosis. If the elbow is ankylosed in extension and the triceps is contracted, the triceps aponeurosis is dissected distally as a tongue from the triceps muscle, being left attached to the olecranon. An incision is then made in the midline of the triceps muscle and through the periosteum to the humerus. When the joint is ankylosed at a position of 90 degrees, lengthening of the triceps is not necessary. In such cases, the triceps aponeurosis is incised longitudinally and retracted along with the triceps muscle (Fig. 27).

The periosteum overlying the posterolateral border of the olecranon is incised and the expanded lower end of the humerus and the olecranon are exposed subperiosteally. The head of the radius is now cleared, and the ankylosis is severed with an osteotome. It is necessary to avoid injury to the ulnar nerve, and, if desired, the nerve may be isolated before the ankylosis is severed.

The joint is now flexed and dislocated medially, delivering the lower end of the humerus into the wound. The anterior aspect of the lower end of the humerus is exposed subperiosteally, this exposure being minimal in order to interfere as little as possible with the circulation to the bone and thus prevent excess bone absorption postoperatively. A simple monocondylar articulation is now fashioned with an osteotome, no attempt being made to reproduce the contour of the capitellum and trochlea. Ordinarily, sufficient bone is removed to create a ½ inch joint space. Under no circumstances is resection above the condyles permitted, since a disabling degree of disability will result owing to the loss of the stabilizing influence of the condyles.

Attention is now turned to the olecranon and radius. The sigmoid cavity is now re-formed, using a curved gouge. If the head of the radius is fused to the



Fig. 29.—Arthroplasty of the elbow, 11 years after operation. The elbow is strong, stable, and painless. Note the range of motion. Considerable proliferative changes are present.

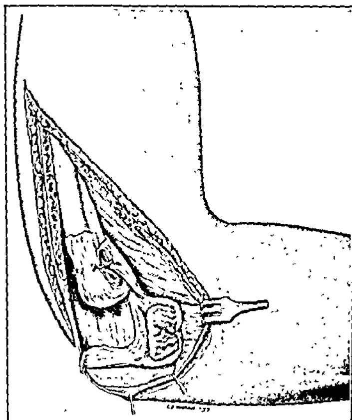


Fig. 28.—Arthroplasty of the elbow; the operation is completed. The joint is re-formed and fascia lata is interposed between the articular surfaces of the ulna and humerus, and of the radius and ulna.
(Speed, J. S., and Smith, H. [Eds.]: *Campbell's Operative Orthopedics*. C. V. Mosby Co., 1949.)

it may be fixed in position by sutures passed through small drill holes placed through the medial and lateral edges of the humerus, which at that point are thin and sharp.

The olecranon fossa and head of the radius are covered by the lower half of the fascial transplant, forming the reflections similar to the normal joint. The fascia is reflected between the radius and ulna, the head of the radius being covered and the fascia anchored to it in a purse-string manner.

The joint is now reduced and the capsule is closed with interrupted sutures, the elbow being held at a right angle. The divided edges of the triceps muscle are approximated with interrupted sutures and the aponeurosis is replaced, its position in relationship to the muscle itself depending on whether lengthening of the triceps tendon is necessary because of contracture of the muscle. In effect, this incision permits a Z-plastic lengthening of the triceps muscle.

After-care. The elbow is immobilized in a right-angle posterior elbow splint or long arm cast, on an abduction humerus splint to prevent rotation, for 10 to 14 days. When wound healing is complete, the abduction humerus splint is discarded, and the elbow splint or cast is removed. The arm is left free for periods of one to two hours three to four times a day, so that active exercise can re-

TECHNIC (FOWLER)

A longitudinal dorsolateral incision approximately 2 inches in length is made in the interval between the interosseous and extensor tendons. The extensor tendon is freed from any adhesions to the metacarpal bone, but its attachments to the phalanx are not disturbed. A new joint space is forced by excision of a segment of the base of the proximal phalanx. The metacarpal head is fashioned in a chisel-like manner, inclining volarward, and being tapered sharply in an anteroposterior direction. Laterally, the reconstructed articular surface remains broad and flat. No attempt is made to create any concavity of the proximal phalangeal articular surface (Fig. 31).

The fascia from the anterior aspect of the upper forearm or paratenon from over the fascia lata on the anterolateral surface of the distal third of the thigh forms the most satisfactory interposing membrane in this joint. The membrane is folded between the joint surfaces, beneath the extensor tendon proximal to the joint, and deep to the tendons of the interossei (Fig. 32).

Where there is loss of intrinsic muscle function, the tendon of the flexor digitorum sublimis muscle should be removed from its sheath, rerouted through the lumbrical tunnels on either side of the affected joint, and sutured to the extensor aponeurosis on either side of the proximal phalanx, after the manner described by Bunnell.

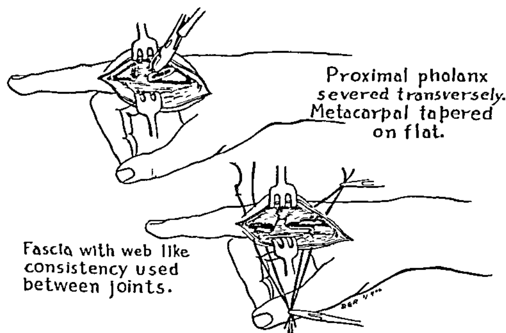


FIG. 31.—Arthroplasty of the metacarpophalangeal joint space (Fowler). The proximal phalanx is divided transversely, the metacarpal head tapered on flat. Note the method of fascial interposition.

(Fowler, S. B.: *J. Bone & Joint Surg.*, 29:193, 1947.)

develop the flexors and extensors of the elbow, and for physical therapy. Between exercise periods and at night, a posterior elbow splint with straps and buckles is worn. After two to three weeks, the splint can be entirely discarded during the day, using a sling for support. Use of the splint at night should be continued until a useful range of motion, with good strength, has been regained. Ordinarily, the night splint can be discontinued about eight weeks following operation. *The patient must continue active exercises for a period of at least six* months. Though maximal strength and motion are usually regained within two years after operation, the patient must be followed at least five years before any definite conclusions as to the end-result can be formulated (Figs. 29 and 30).



FIG. 30.—Arthroplasty of the elbow, 11 years after operation. Arthroplasty was performed for *solid bony ankylosis due to acute infectious polyarthritis. Motion was present from 55 degrees* to 155 degrees; good strength and stability; no pain.

ARTHROPLASTY OF THE METACARPOPHALANGEAL JOINTS

Of the joints of the hand, only the metacarpophalangeal joints of the fingers lend themselves successfully to arthroplasty. The procedure is indicated where there is a destructive lesion of the joint with a residual of less than 30 degrees of motion in a useful range, and where mobilization of the joint will restore the hand to usefulness. The procedure is contraindicated if the finger is permanently anesthetic, if there is marked deformity, or if flexor tendons are absent. Where the metacarpal is markedly shortened, arthrodesis of the joint is to be preferred, all things being equal.

The technic described by Fowler has proved most satisfactory in our hands, and is now used in our clinic. An average of 70 degrees of motion with good stability may be obtained by this method in proper selected cases.

After-care. A short forearm and hand cast is applied, incorporating traction to the operated fingers with the metacarpophalangeal joints maintained in a position of 60 degrees of flexion. One week after operation, the cast is removed and joint mobilization is begun. Between exercise periods and at night, a protective aluminum hand and finger splint is applied. After three weeks, all external support may be removed and the exercises are increased in number and vigor. If any difficulty is encountered in obtaining full flexion, the removable "knuckle-bender" splint described by Bunnell is applied to increase the range of motion. This splint is worn at regular intervals, and as flexion is increased, the splint is gradually discontinued.

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Fig. 32.—Metacarpophalangeal arthroplasty, performed according to the technic of Fowler. (A) Preoperative appearance of bone; there was painful partial ankylosis secondary to gonorrheal infection. (B) One month after operation. (C) One year after operation. Motion now present from 180 degrees extension to 110 degrees, with no pain. The patient has returned to work as a truck driver without disability.



Fig. 1.—Marked asymptomatic bilateral upper tract dilatation in adult life. (A) Cystogram. (B) Post-mortem pyelogram.

Congenital Ureteral and Pelvic Dilatation as Evidence of Obstruction

FRANK HINMAN, JR., M.D.

If obstruction could be shown to account for most, if not all, cases of megalo-ureter and hydro-ureter in the fetus and infant, as it does in the adult, urologic treatment would be simpler. To establish the primacy of obstruction, two things must be proved: (1) that renal function does indeed occur in utero; (2) that a definite obstructive lesion can be found. The less obvious obstructive lesions must be located by deduction, since the changes above them are in every way similar to those due to the demonstrable obstructive lesion. We must conclude that the obstructive factor has been outgrown or destroyed.

FETAL RENAL FUNCTION

Clinical Evidence

The evidence for fetal renal function is overwhelming. Why then is there a question? The answer may be given readily: infants have been born with no detectable site for egress of urine and without evidence of dilatation of the bladder or of the ureters and kidneys. J. von Englisch, in 1881, reviewed 39 cases of urethral occlusion and decided that the placenta removes the wastes in case of block of the excretory passages. He stated, however, that in general, if the urethra is closed and there is no abnormal opening, the dilatation of the kidney and bladder is so great that life is not possible. Most of the reports he assembled, nevertheless, described urethral block with dilatation above. The exceptions to the expected finding of dilatation must be reviewed and explained. Menegaux and Boidot, after assembling the literature on congenital urethral occlusion up to 1934, concluded that if the child is born alive, suppression of fetal function has occurred and retention will not be found. The 11 case reports available to illustrate this (Balard; Birdsall; Dourmashkin; Goodyear; Marquardt and Frederick; Östling; Textor) are of infants who usually required vigorous urethral sounding to break through the urethral obstruction. Lacking are simultaneous studies of the upper tract; all that is reported is the absence of palpable or visible dilatation of the bladder and the absence of deleterious clinical effects. We are familiar with advanced cases of congenital hydronephrosis, even in the adult, without outward signs of disease (Fig. 1). The possibility of a patent urachus, or of a rectovesical or recto-urethral fistula must not be overlooked (Campbell, 1937; Rublach). Other explanations might include almost complete urethral stenosis through which small amounts of urine might leak before birth. Also, obstruction at or just before birth by desquamated squamous urethral epithelium from stimulation by maternal estrogens might account for the newborn child without

TABLE I

Author, Year	*Site of Obstruction*	*Effect of Obstruction*
Boudin, 1881	Atresia of fossa navicularis and anus	Dilatation of ureters
Delbovier, 1881	Urethral stenosis	Dilatation of bladder
Delpech, 1881	Urethral atresia	Hydronephrosis
Depaul, 1881	Urethral stenosis with rectovesical fistula	Vesical and ureteral dilatation
Duncan, 1881	Vesicocolic fistula	Dilatation of bladder, left hydronephrosis
Duparque, 1881	Urethral and urachal occlusion	Dilatation of bladder and ureters with hydronephrosis
Ebert, 1881	Urethral stenosis	Dilatation of bladder
Fearn, 1881	Urethral stenosis	Dilatation of ureters & hydronephrosis
Freund, 1881	Urethral atresia	Vesical dilatation
Hecker, 1881	Urethral atresia	Dilatation of bladder
Ivanoe, 1881	Atresia of fossa navicularis	Dilatation of ureters
Janny, 1881	Atresia of urethra	Dilatation of bladder
Moreau, 1881	Atresia of pars prostatica	Dilatation of bladder, ureters, kidney
Stilling, 1881	Atresia of urethra	Dilatation of bladder
Skene, 1887	Atresia of urethra	Abdominal distention due to dilated bladder
Rose, 1887	Absence of urethra	Marked dilatation of bladder and kidneys
Middleton, 1887	Absent urethra	Release of urine with trochar
Cunningham, 1907	Imperforate urethra	Dilatation of bladder, ureters, kidney
Brown, 1923	Imperforate urethra	Dilatation of bladder
Pfaundler and Schlossman, 1932	Posterior urethral valve	Dilated bladder, ureters, renal pelvis
Randall, 1930	Posterior urethral valve	Dilatation of bladder, ureters, kidney
Bar, 1934	Obstruction at external urethral orifice	Distention of mid and upper urinary tract
Leonard, 1934	Urethral stenosis	Distention of bladder
Olshausen, 1934	Obliteration of anus and urethra with vesico-utero-colic fistula	Dilatation of bladder, ureters, kidney
Wittaker, 1934	Absent genitalia	Greatly dilated bladder with abdominal distention
Savage, 1935	Incomplete urethral obstruction	Dystocia due to vesical dilatation
Woodruff and Milbert, 1937	Complete urethral atresia	Dilated, tortuous ureters, and hydronephrosis
Thierstein et al., 1948	Possible urethral obstruction	Dilated bladder (4,200 cc.) containing calcified deposits
Jorup and Kjellberg, 1948	Posterior urethral valves	Abdominal distention with renal and ureteral dilatation

palpable vesical dilatation who fails to void. So many instances of similar complete obstruction with marked retention of urine have been reported, that these cases without evidence of dilatation prove at most that (1) fetal renal excretion is not essential to life (in the normal fetus the waste products are merely reabsorbed from the amniotic fluid), and (2) gross vesical distention and upper tract dilatation do not necessarily follow complete obstruction in the fetus.

The converse cases, however, in which obstruction was followed by dilatation are legion. We may list the most interesting ones in Table I.

A typical case of our own, seeming to prove fetal renal function, is illustrated in Figs. 2A and B. The obstetrician noted that the mother had abnormal enlargement of the uterus as early as five months. At birth, the child had a protuberant abdomen and hematuria. Cystoscopy at four days of age was difficult because of diffuse constriction and fixation of the posterior urethra. Uremia was progressive and the child died on the 15th day of life. Autopsy showed a hypertrophic but contracted bladder, bilaterally dilated ureters and pelves, with advanced destruction of the renal parenchyma.

Obstruction to urinary flow is the only reasonable explanation for these cases which form the strongest clinical evidence for fetal renal function.

Experimental Evidence

Renal function in fetal life has been demonstrated experimentally by many technics.

An analogy with other animals was drawn by Windle between the well developed allantois in birds, which reabsorbs the water so necessary to the isolated developing chick, and the allantois in man, which is vestigial. A well developed placenta takes its place in handling the exchange of fluids. Bremer similarly contrasted the large allantois with thick placental barriers in the pig, sheep, and cat to the degenerate allantois and well differentiated, delicate placental wall in man.

Analysis of the normal bladder and amniotic fluid gives evidence of renal function. Wöhler, in 1846, found a uric acid stone in a stillborn fetus, which he interpreted as evidence of the fetal excretion of uric acid. Portal in the 17th century (according to Williams) suggested that the amniotic fluid represented fetal urine. Zangemeister and Meissl, in 1903, in a definitive piece of work based on determination of freezing point, osmotic pressure, and direct analysis for chemical constituents, found that the amniotic fluid was always hypotonic, so that at term 16.5 per cent of the amniotic fluid was fetal urine. Their data show that this urinary secretion began as early as the fifth month. Confirmation has come from several workers (Bialascewicz; Grunbaum; Jacque; Lewis; Makepeace; McCance, 1948, 1950, Reinwein and Heinlein; Tausch; Uyeno). These observations dovetail with those of McCance and others that urine passed in utero is more dilute but otherwise the same as that formed in the first few days of life (Barta and Hernadi; Gordon et al.; Rubin et al.; West et al.).

Function tests, applied in utero, prove renal excretion. Substances injected into the pregnant woman have been recovered in the amniotic sac (Gusserow), and in the fetal urine itself (Butler). Indigo appears in convoluted tubules of dogs at term 25 minutes after injection (Bar; Wiener); sodium ferricyanide and iron

of excretion." By staining methods, Hewer found indications of renal function probably as early as the ninth week, and certainly by the 12th week. Human tubular cells secrete in tissue culture (Cameron and Chambers).

Roentgenographic evidence was obtained by Kjellberg and Rudhe by urograms at cesarean section in the fourth to fifth month of pregnancy. The films showed secretion of diodrast by the kidney.

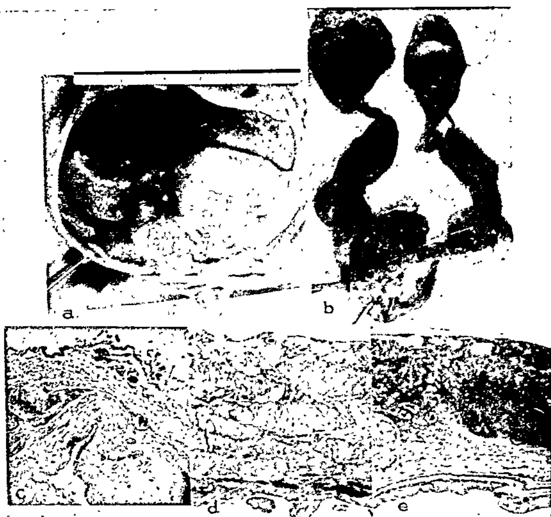


Fig. 2B.—Autopsy findings in case shown in Fig. 2A, as evidence of fetal renal function. (a) and (b) Gross changes: marked ureteral and pelvic dilatation with advanced parynchymal changes; hypertrophic bladder. Microscopic changes in (c) ureteral wall, (d) vesical wall, and (e) renal cortex.

Experimental obstruction of the excretory ducts (mesonephric ducts) in the chick embryo caused proximal dilatation, and occlusion of a tubular segment allowed concentration of externally applied phenol red within the lumen (Boyden). Wells, in a series of classical experiments, blocked the urethra of unborn rats 16 hours before term, then placed the fetuses in the abdominal cavity. At term, the urinary tract above the point of ligation was distended in each animal. In addition, phenolsulphonphthalein injected into the fetus at the time of operation was found

ammonium citrate appear as prussian blue in the convoluted tubules of the fetal cat from five to several hours after introduction in the umbilical artery. This may occur early in fetal life (Firket). Phenolsulphonphthalein, trypan blue (Wislocki), and other vital dyes (Keene and Hewer) are similarly excreted. Gersch found by these methods that even the mesonephroi function and excrete simultaneously with the metanephroi. His work indicates that tubular function begins in the human embryo at 32 mm. (nine weeks). Confirming evidence was obtained earlier (Ballantyne; Wagner) in the demonstration that fetal function occurred

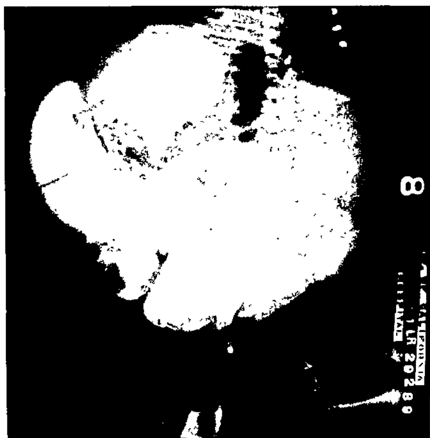


Fig 2A.—Cystogram with reflux in a 15 day old male infant.

if there was maternal renal insufficiency. Further measurements include the detection of a low glomerular capillary pressure. The only contradictory evidence, and that not convincing, came from Schaller. He gave phloridzin, found little sugar in the amniotic fluid, and concluded on this evidence that there was little or no renal function.

Cytologic evidence supports the concept of fetal renal function. Histologically, mesonephric tubules are capable of functioning since they persist intact with glomeruli and tubules to nine weeks (Altschule). Metanephric glomeruli continue to develop to the 35th week (Potter and Thierstein). Krafka notes that "sections of an 18 mm. embryo [six weeks] give convincing cytological evidence

of Brown is in a report of the familial incidence of megalo-ureter in 3 of 7 human siblings (MacMyn). Examples of ureteral obstruction causing proximal dilatation are not hard to find (Howze and Hill). The ureterocele with upper tract dilatation is common. Even the 47 cm. fetus with segmental obliteration of the ureter may show dilatation and hydronephrosis (Thiemann).

Mid-tract Obstruction and Incompetent Ureterovesical Orifice

Neurogenic bladder and incompetency of the ureterovesical orifice can result in upper tract dilatation. That reflux of urine occurs with the cord bladder has been shown (Kretschmer and Hibbs; Pfeffer; Talbot and Bunts). In these cases, the reflux is perhaps due to distortion of the orifice secondary to infection and detrusor hypertrophy (Hagner). Among normal individuals, reflux is more common in children (Andler; Gibson; Kretschmer, 1915, 1916) than adults (Young), and is a normal finding in some animals (Semblinow), but not in others (Sampson). Gruber showed that reflux is dependent on three factors: the length of the valve, the degree of development of Bell's muscle, and the thickness of the bladder wall. The experimental section of the valve at the orifice with the help of local fibrosis allows urinary reflux and resultant hydro-ureter, often with reverse peristalsis (Gruber, 1930). However, ureteral peristalsis forms a secondary defense against reflux (Draper and Braasch). Of course, reflux is not essential to the development of upper tract dilatation with distal obstruction (Kearns and Jacobson), and, conversely, reflux may be found in a patient with no obvious distal obstruction (Ahlfeld; Couvelaire; Grant; Heymann and Martin; Longridge; Williams). These cases confuse the distinction between "megalo-ureter" and hydro-ureter, for it is so often assumed by the physician that the dilatation must be primary in the ureter. However, the fact of reflux plus the invariable finding of work-hypertrophy of the ureteral wall and dilatation or hypertrophy of the bladder force us to agree with MacMyn that in most of these cases obstruction in the posterior urethra (valves and folds) is overlooked, outgrown, or destroyed by diagnostic instrumentation. The rest of the cases of bilateral upper tract dilatation fit in the group of neurogenic bladder occurring secondary to spina bifida or other cord lesion. Unilateral dilatation does not argue against this interpretation, since one ureteral orifice may be affected before its mate (Hilliard; Marti). We saw a patient recently in whom one orifice has regained competency after cystostomy while reflux continues up the other orifice. Reflux in the newborn then, when coupled with some form of distal obstruction, is added proof of fetal renal function, and consequently of the obstructive nature of the ureteral dilatation in this syndrome.

Lower Tract Obstruction

Lower tract obstruction is the common and accepted cause of hydro-ureter, and affords excellent clinical proof of fetal renal function. We have already described the cases of congenital atresia of the urethra which were followed by middle and upper tract dilatation. This evidence is difficult to refute. Cases are reported with overdistended bladder and dilated upper tracts (Currie) without the obstructive lesion being found. We would conclude that either the obstructive lesion has been destroyed by instrumentation, was by nature temporary,

in the fetal urine. He was able to accelerate the process of dilatation by bilateral ureteral ligation in the mother, or by the injection of urea as a diuretic into the fetus.

A different technic, using roentgen radiation of the parents to cause hereditary ureteral anomalies in rats, was developed by Brown. The resulting ureterovesical juncture obstructions showed that proximal dilatation (hence function) occurs on the 15th to 16th day of gestation, and by the 19th to 25th day either the hydronephrosis resolves by spontaneous release of the obstruction or it becomes permanently established.

From these various experimental sources we reach the inescapable conclusion that fetal renal function does occur, and, even though not essential to fetal life, is a normal phase of embryologic development.

THE OBSTRUCTIVE LESION

An obstructive lesion is necessary to block the fetal renal secretion and so cause the observed dilatation. The evidence for such obstruction obtained from experimental and clinical observations falls easily under three headings: (1) ureteral obstruction, (2) mid-tract obstruction (which includes neurogenic bladder and incompetency of the ureterovesical orifice), and (3) lower tract obstruction. We shall not discuss here the common ureteropelvic juncture obstruction.

Ureteral Obstruction

Ureteral obstruction is best explained by the embryologic work of Chwalla, who found a ureterovesical membrane as a normal occurrence during the separation of the ureteral bud from the wolffian duct. Persistence of this membrane would cause ureteral obstruction by constriction or by a valve action (Boyden; Vermooten, 1939). The dilatation secondary to such obstruction then would be brought about by several factors. Renal secretion we have already discussed. Intra-ureteral pressure, the second factor, lasts as long as the muscles of the renal pelvis, calyces, and ureter act (Rényi-Vámos) and, as shown by acute experiments, rises higher than can be explained by renal secretory pressure alone (Henderson) (ureteral activity alone may raise a column of water over 35 cm.—Gruber, 1930). Ureteral peristaltic contraction is dependent on stretch (urine flow) (Bozler), but diminishes after a crucial level of pressure is reached (3 to 18 cm. water) (Trattner). It may pass a point of partial obstruction with diminished amplitude (Wislocki and O'Conor). Peristalsis is impaired early in dilatation (Quinby). Instrumental ureteral dilatation causes ureteral dilatation and hypertrophy, with hydronephrosis secondary to this functional block (Greene). Consequently, when embryologic ureteral obstruction occurs there is first hyperactivity resulting in muscular hypertrophy and elongation (Vermooten, 1930), then dilatation as the muscle decompensates, and, finally, atony. The reaction of the ureteral and pelvic musculature in infants to work is much more intense than in adults (Maatz). Portions of such a sequence were seen by Brown in abnormal rat fetuses, by Wells experimentally, and were deduced by Grauhan to occur in the human fetus. A series similar to the experimental animals

Can we reconcile idiopathic or purely developmental ureteral sacculation and dilatation (often with the patent ureteral orifice and with hydronephrosis)—usually called "megalo-ureter"—with the obviously obstructive hydro-ureter and hydronephrosis caused by meatal stenosis, posterior urethral valves, or stenosis at the ureterovesical junction—typically "hydro-ureter"?

Definitions for Megalo-ureter and Hydro-ureter

Megalo-ureter must first be identified. The conflicting definitions themselves make the condition suspect as an entity. The list begins with Saintu, although he did not use the term. His case, through Caulk, is commonly accepted as the classic example. Note that his patient was a newborn child, delivered with difficulty because of a dilated bladder, who voided spontaneously but died in a few days. Autopsy revealed dilated ureters but grossly normal kidneys. Saintu concluded the syndrome was due to defective innervation of the bladder itself. Caulk, on the other hand, although referring to Saintu, coined "megalo-ureter" to describe the ureters in his own case: an infant with a dilated, tortuous right ureter without pelvic dilatation, but with improvement after ureteral meatotomy. He felt that he was dealing with a primary defect in the ureteral wall, and that obstruction played no part (even though improvement followed his operative procedure).

So we see how confusion entered and the following incomplete listing merely compounds that confusion:

Saintu, 1896: dilated ureters with normal calyces, due to neurogenic bladder
Papin and Legueu, 1912: dilated ureteral orifices with reflux
Caulk, 1923: dilated tortuous ureter with narrow orifice, due to primary anatomic defect in ureteral wall
Eisenstadt, 1926: dilated bladder and calyces and tortuous, dilated ureters with reflux, due to deficient muscular development
Hinman, 1929: dilated ureters without hypertrophy of wall, tortuosity or elongation
Campbell, M. F., 1939: dilated ureters with or without ureteral stricture, like congenital esophageal stricture.
Irvin and Kraus, 1948: large bladder with dilated, tortuous thick ureters, due to achalasia or paralysis of ureterovesical sphincter.
Campbell, E. W., 1948: dilated ureter with atonic orifice and dilated renal pelvis (sic!), as described by Saintu in contrast to the dilated ureter with narrow terminal spindle called metalo-ureter by Caulk, 1923.
Wayman, 1949: dilated, nontortuous ureter (attributed to Caulk, 1923)

Note how the meaning varies from ureterectasis alone (Saintu) to ureterectasis plus caliectasis with reflux (Papin and Legueu), and from straight, nonhypertrophic ureters (Hinman) to tortuous, hypertrophied ureters (Irvin and Kraus). The only possible point of general agreement is that megalo-ureter is not the result of a demonstrable obstructive lesion, but Caulk's original case refutes this, and others apparently are not convinced of it. In 30 years at the University of California Hospital, only one case has been seen which really fits the requirement of dilated ureter without caliectasis, and this patient was benefited by

or that the defect was due to a neurogenic bladder. Campbell proposes an alternative explanation: "In the light of recent clinical observation it seems certain that some instances of apparent congenital ureteral dilatation, the dilatation of the upper urinary tract results from primary backpressure induced by obstructive sphinctero-spasm at the bladder outlet."

An interesting alternative explanation for the case of upper and middle tract dilatation without cystoscopic evidence of an obstructive lesion has already been briefly mentioned. Squamous metaplasia caused by maternal estrogens may in some cases be obstructive. Englisch as long ago as 1873 felt there was a correlation between the distention of the prostatic utricle and the period of intrauterine life, but Lacassagne first showed experimentally the correlation between high doses of estrogen and squamous metaplasia of the müllerian elements of the posterior urethra. Further he noted urinary retention and hydronephrosis in the guinea pig after five months' treatment. These findings have been repeatedly confirmed (Burrows and Kennaway; Menke; Nanson). Hydronephrosis in infancy has been described by Bugbee and Wollstein, one of whose cases had peeling stratified epithelium on the large obstructive verumontanum. Squamous metaplasia is the common finding in the human fetus, being found even in the 23 cm. embryo (Brody and Goldman). Consequently, since such metaplasia from stimulation by maternal estrogens occurs and since obstruction can result from this source in experimental animals and since cases of hydronephrosis have been reported which are best explained on this basis, it could be argued that such a cause may operate when unexplained dilatation of the urinary tract responds to simple urethral instrumentation or to no treatment at all.

THE CAUSES OF URETERAL DILATATION (MEGALO-URETER VS HYDRO-URETER)

If we agree that fetal renal function occurs, that the dilatation of the upper urinary tract in any given case is indistinguishable from that secondary to a demonstrated obstructive lesion, and that in the majority of cases such obstructive lesions are found, then we are in a position to question the findings of those who postulate a nonobstructive origin for such upper tract dilatation.

Consider the various factors used to explain the megalo-ureter: congenitally deficient nerve supply, agenesis of the muscular coats, spontaneous reflux. How can a child with a dilated upper tract be rationally treated if so many apparently unrelated factors must be considered, factors which would not respond to urologic treatment? Dilatation from an obstructive lesion can be treated by known urologic procedures; if from neuromuscular deficiency or ureteral dysgenesis, it cannot. I believe the following review of all factors makes obstruction the one common denominator for all cases of upper tract dilatation in children as in adults.

We do not concern ourselves with congenital hydronephrosis caused by ureteropelvic juncture abnormality, since this is accepted as due to local obstruction. However, unilateral or bilateral, localized or complete dilatation of the upper urinary tract has not been so obviously obstructive in causation. Spontaneous reflux and megalo-ureter should fit in a reasonable scheme to allow us to apply reasonable and hence effective treatment.

Neuromuscular Dysfunction. The analogy of congenital ureteral dilatation with dilatations of the esophagus and colon was first suggested by Bard in 1920, and others have made a similar comparison (Etala; Etzel; Hepler; Hurst and Gaymer-Jones; Lehmann). It is of interest that as long ago as 1900, it was suggested (Thompson) that a disturbed or deficient nervous mechanism might account for dilated ureters without detectable lower tract obstruction. Two cases of megalo-ureter reported three years ago (Carver) are typical of those ascribed to neuromuscular imbalance. Previous to that time experiments which stripped the ureter of its nerve supply in the experimental animal, caused hydronephrosis (Stewart and Barber). This suggested an "adynamic ureter" as the cause of the dilatation. But injury and fibrosis of the intrinsic neurosmuscular synapses secondary to the operative procedure rather than loss of the extrinsic nerve supply might be a better explanation when one considers the work which shows that ureteral tone and peristalsis are independent of the extrinsic nerve supply (Engelmann; Lapides). In addition, others have found that experimentally one cannot get ureteral dilatation by simple denervation (Östling). Inflammation has been blamed (Beer; Braasch; Karaffa-Korbutt) but inflammation without obstruction would be expected to cause stricture rather than dilatation (Campbell, 1937). The inflammatory changes found at operation can better be ascribed to the secondary infection promoted by the stasis.

Contradicting the conclusions drawn from certain of these experimental and clinical observations of deficient innervation is the almost invariable finding of hypertrophy of the ureteral musculature (Campbell, 1948; MacMyn). In the rare case without histologic evidence of smooth muscle thickening, there is definite evidence of obstruction with secondary dilatation and fibrosis (Irvin and Kraus). Reported cases of dilated ureter without renal agenesis (Clark; Deilmann; Huff and Boger; Meade; Textor) or hypoplasia uniformly have stenosis or absence of the ureterovesical junction. If the orifice is patent, dilatation is absent (Gloor). With renal agenesis, ureteral dilatation does not occur, even though such agenesis is an example of abnormality of the ureteral bud rather than of the renal blastema (Hamilton). Achalasia, likewise, is an inadequate concept since the ureter has no important extrinsic nerve supply which could become "imbalanced" and result in closure of the ureterovesical orifice simultaneously with descent of the peristaltic wave. On the contrary, most of the reported cases due to neuromuscular dysfunction also had neurogenic bladders (obstructive in themselves) or actual ureteral stenosis. Obstruction therefore will best explain the findings in this group.

Congenital Anatomic Defect in the Ureteral Wall. Dissection of human embryos has shown that muscle grows into the ureteral bulb secondarily, so that it does not appear until the eighth week (Gerard). Even at five months the ureteral bud is wide and large. The conclusion was that a congenitally thick ureter was the result of lack of inhibition of ureteral growth, while inhibition of development of the muscle caused a thin-walled ureter. Others have concurred, feeling that the fault lay in absence of muscular development at the distal end of the ureter and that dilatation was due to a primary disturbance of ureteral growth (Gaudino; Kermauner). It was left for Östling to summarize the findings by a collection of casts of fetal and neonatal ureters. He stated definitely

dilatation of the ureterovesical orifice (Fig. 3). Other similar cases have been described (Grajewski; Meuser).



FIG. 3.—Pyelogram illustrating ureteral dilatation without pelvic or calyceal enlargement.

THEORIES OF ETIOLOGY

Let us go back then and consider the proposed theories which account for a dilated ureter. These are three:

(1) neuromuscular dysfunction of the ureter and/or its orifice;
(2) congenital anatomic defect in the ureteral wall;
(3) congenital obstruction, already discussed, predicated on fetal renal function.



Fig. 4.—L. A. W., female aged one year (1947). Marked bilateral hydronephrosis with dilated ureters; no lower tract obstruction detected; no treatment. PSP excretion one year later rose to 50 per cent in two hours; continued improvement since then. (A) Retrograde urogram, 1947. (B) Retrograde urogram, 1948. (C) Intravenous urogram, 1951.

that (assuming as he did that no fetal renal function occurs) these congenital dilatations were due to differential growth disturbances during fetal life.

Several facts are against such a conclusion. Loraine found dilated ureters up to the fourth or fifth month and suggested this was a usual occurrence which regressed as normal development was completed. Besides, if arrested local muscular development were the cause, one would expect to find deficient musculature in the distal ureter. Such is seldom or never the case (Campbell, 1948; MacMyn). Östling has built his case on the assumption that there is no fetal renal secretion. We have shown that this assumption is unwarranted. As for his statistical finding of a higher incidence of dilatations among fetal specimens than after birth (if this is any evidence of the origin of the much greater dilatations of infancy), perhaps this can be explained by a mechanism to my knowledge not previously advanced—an effect of the maternal hormones.

The role of placental hormones in the ureteral atony and dilatation of pregnancy is well established (Jenkins and van Wagenen; Traut and Kuder). Why could not this action affect the fetal ureter as well? Traut, in certain unpublished experiments in dogs, found that ureteral activity in fetal dogs in response to stimulation closely paralleled the decreased activity found in the maternal ureter. Since renal secretion occurs during fetal life, it is easy to interpret these so-called developmental, almost physiologic, dilatations during midfetal life as similar to those noted in the mother during pregnancy. If the occasional obstructive lesion should occur by developmental aberration (ureterovesical or urethral stenosis, for example), then the common fetal dilatation would persist into neonatal life.

Congenital Obstruction. We have already discussed the effects of actual obstruction. To summarize: in the presence of fetal renal function and with the occurrence of upper tract dilatation similar to the various types known to come from distal obstruction, the exceptions to the common finding of a definite obstructing lesion can best be explained either by its prior destruction or by spontaneous resolution.

CLINICAL APPLICATION

We may fairly conclude from the clinical and experimental data assembled above (1) that fetal renal function does occur, and (2) that obstruction to such excretion may result in dilatation of the renal pelvis, ureter, or bladder, or to all three. The importance of these conclusions lies in their application to the clinical problem. They force the urologist to search out and relieve the obstructive factor. A breakdown of the sites of obstruction from Campbell is as follows: ureteropelvic junction, 28 per cent; body of ureter, 13 per cent; ureterovesical junction, 62 per cent; vesical neck, 15 per cent; urethra, 8 per cent (including cases with more than one obstructive site). The embryologic anatomic causes of the obstruction at these sites are many and varied. The reader is referred to the tables in Campbell's text (1951). The important object in treatment is not so much using the exact technic to correct the embryologic error, but rather to apply approved urologic methods to either bypass the obstructive lesion or to re-establish the normal lumen of the urinary tract.

Transurethral fulguration and resection are required more frequently, especially in older children, in whom the obstruction is less complete and more resistant (Fig. 6). Residual urine persists after catheterization or dilatation. Endoscopic visualization of the posterior urethra reveals valves or diaphragm, or more often, elevation of the posterior lip with a generally contracted vesical neck. Transurethral incision, fulguration, or resection with Colling's knife or infant resectoscope, often to be followed by the intermittent passage of sounds, is necessary.

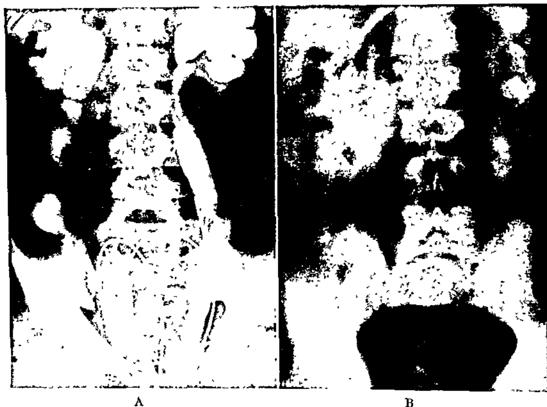


Fig. 6.—G. J., Male, eight years old in 1947. Enuresis was the only complaint. Residual urine 250 cc., PSP 57 per cent. Cystoscopy revealed slightly dilated orifices and a bar at the vesical neck. The bar was resected via perineal urethrotomy with a 27 F Nesbit resectoscope. Residual urine was now 14 cc, renal function unchanged. (A) Retrograde urogram on entry; no recent change. (B) Intravenous urogram at present (four years later).

Ureteral meatotomy, for obstruction at the ureterovesical junction, as ureterocele or stricture, will allow free egress of the urine, but unfortunately also allows reflux up the ureter. However, if the vesical reflex is normal and no lower tract obstruction exists, the orifice often will regain its competency (Fig. 7).

Pyelo-ureteroplasty is necessary for release of ureteropelvic juncture obstructions. If performed over a splint, the exact technic of suture is of less importance than an adequate stoma (Fig. 8). Partial ureterectomy for ureteral redundancy has not been particularly successful (Fig. 9).

Treatment may be intended either to remove the obstruction, or to bypass it. We have used everyday cases for the illustration of the various forms of treatment, without regard for the final therapeutic result. They give a fairer view of treatment than would cases selected only for a good outcome.

TREATMENT DIRECTED AT THE OBSTRUCTION ITSELF

Simple catheterization, or diagnostic instrumentation as we have already commented, may be treatment enough in those patients with upper tract dilatation in whom no posterior urethral obstruction can be found after withdrawal of residual urine or inspection of the bladder. In other words, the obstructive valve or fold or narrowing has been destroyed by simply passing the catheter (Fig. 4).



FIG. 5.—B. G., female, aged 10 months when seen in 1948. Hypertrophy and contracture of the bladder neck, dilated bladder with residual urine and with dilated right ureteral orifice and reflux. She was treated for two years by intermittent urethral dilatation, with clearing of urine, restoration of right ureterovesical orifice, and loss of dilatation of the right upper tract. The right kidney is however functionally more atrophic. (A) Retrograde urogram before treatment. (B) Retrograde urogram after treatment, 1951.

Repeated urethral dilatation with metal sounds up to 20-22 F. may be effective treatment in girls with residual urine and not too severe upper tract damage (Fig. 5). It is less effective in boys.

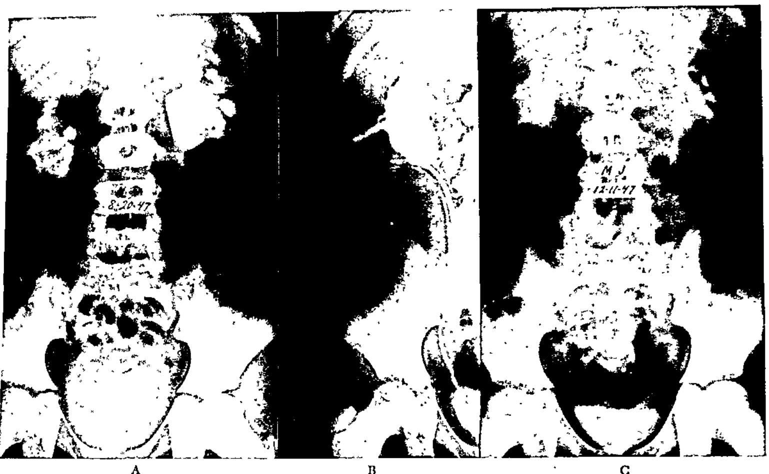


Fig. 8.—M. J., female aged eight when seen in 1947. She entered the hospital because of recurrent vomiting and swelling in the right flank. The urine was normal, PSP excretion 52 per cent in one hour. Bilateral pyelo-ureteroplastics over 18 F. catheters as splints. Final PSP excretion 85 per cent in one hour. (A) Preoperative intravenous urogram. (B) Detail of right ureteral splint. (C) Postoperative intravenous urogram.

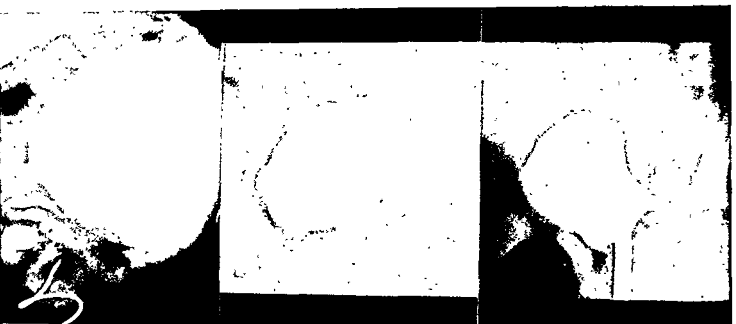


Fig. 7.—L. B., female aged four and one half months when seen in 1947. Because of a protruding abdomen since birth, retrograde study was done and showed large left hydronephrosis, with double left ureter and intravesical protrusion of both left ureters, typical of ureteroceles. Nephrectomy and partial ureterectomy were performed. The infection persisted, necessitating transurethral destruction of ureteroceles. The urine subsequently was normal. (A) Retrograde urogram. (B) Cystogram before nephrectomy. (C) Cystogram after nephrectomy, showing defect and reflux up the ureteral stump.



FIG. 10.—J. M., female aged eight years (1940); spina bifida with meningocele. Spastic cord bladder with 100 cc. capacity. Bilaterally dilated orifices with reflux on left as shown by cystogram. Treated with retention catheter with improved renal function. Cystogram on entry.

TREATMENT DIRECTED AT BYPASSING THE OBSTRUCTION

Retention catheterization is the simplest treatment for lower tract obstruction and is valuable in cord bladder, especially in girls (Fig. 10). Often three to six months of such treatment will allow the ureteral orifices to become competent so that micturition through the now dilated urethra will not force urine to the kidneys or be incomplete with residual urine. The catheter is changed every two weeks and the healing followed by cystograms and the phenolsulphonphthalein test.

Cystostomy is more often necessary in boys, because of their poorer tolerance for the retention catheter (Fig. 11). Re-evaluation at intervals is necessary to

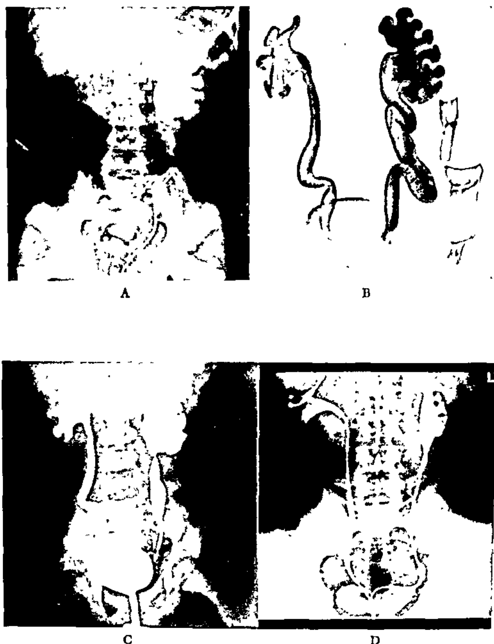
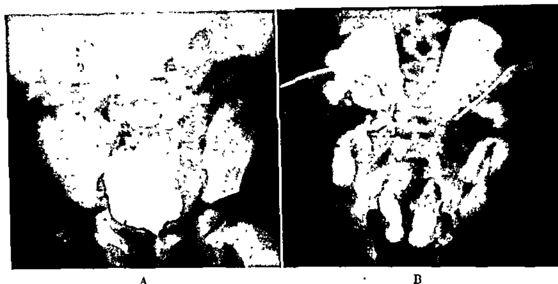


Fig. 9.—W. B., male aged five and one-half years in 1927. Bilateral upper tract obstruction with narrow ureterovesical junctures. Left ureterocystoneostomy was done with resection of portions of the upper and lower left ureter. A recent retrograde study showed no function from the atrophic left kidney. (A) Preoperative retrograde urogram. (B) Drawing of the resected areas. (C) Postoperative retrograde urogram (1927). (D) Pre-nephrectomy retrograde urogram (1951).

preliminary to reimplantation of the ureter, or as an accompaniment of uretero-pyeloplasty, nephrostomy is of great value.

Ureteral transplantation is rarely of value, since the already dilated ureters allow stagnation and reflux. In cord bladder (as with spina bifida) where such diversion would be of most value, the operation cannot be done because of the accompanying rectal incontinence.



A B

Fig. 12.—W. O., male, aged eight months when seen in 1949. He voided more easily after instrumentation of the diaphragm in the posterior urethra. The bladder was thick and trabeculated. Cystograms showed trabeculation but no reflux. Since catheterization of the orifices could not be done and intravenous urograms showed poor function on the right and none on the left, bilateral nephrostomies were done. This was followed by greater improvement on the right than on the left. (A) Cystogram. (B) Bilateral nephrostogram.

CONCLUSION AND SUMMARY

The purpose of searching out etiologic and physiologic, as well as the simpler anatomic, factors in a pathologic process is to allow application of direct and rational methods of treatment. The methods of treatment of renal and ureteral dilatations in the adult patient, based on locating and relieving the obstructive lesion, are accepted and almost standardized. Approaches to relief of such dilatations in infants and children, on the contrary, are hampered by the concept of idiopathic megalo-ureter, for which the surgeon can find no cause and hence is unable to apply a cure.

We have shown that fetal renal function occurs as a normal process, and in sufficient volume to cause typical hydro-ureter and hydronephrosis if its outflow is blocked. Even when the site or structure hindering the urinary flow cannot be found, the changes in the upper urinary tract are indistinguishable from those with a definite obstructive lesion. The probabilities are, by deduction and elimination, that the same forces act in both instances and that the same therapeutic measures of release of the obstruction or diversion of the urinary stream should be applied, thus allowing application of principles of treatment similar to those so well accepted for the adult patient.

determine the optimum time for removal. If such drainage does not restore ureterovesical competency, and the ureteral and pelvic dilatation continues, nephro-ureterectomy may be required. Cystostomy will often allow improvement of the better of the two upper tracts, making removal of the opposite, unimproved kidney and ureter safer and better. However, even the poor side may improve, so that renal counterbalance is arrested and the better side is inhibited in its compensatory hyertrophy, as in Fig. 9. Recently, Swenson has devised a nylon-plug for permanent cystostomy, which could be valuable in the cord bladder.



Fig. 11.—G.A.K., male, aged five years in 1949. Trabeculated bladder without definite evidence of obstruction at the bladder neck. Bilateral hydronephrosis and hydro-ureters with reflux. PSP 45 per cent. Cystostomy was performed. The right side improved markedly, but reflux persisted on the left. Left nephrectomy was finally required to control infection. (A) Cystogram with cystostomy. (B) Retrograde urogram after treatment (1951).

However, clinical application of the device has been hampered by the high incidence of infection-necrosis about the plug.

Ureterostomy and *nephrostomy* are reserved for two situations: the hopeless advanced bilateral case (permanent diversion) (Fig. 12); and the unilateral case with hope for improvement following treatment of the lower or mid tracts (temporary diversion) (see Fig. 5). In general, the life of the patient after bilateral nephrostomy (or the less effective ureterostomy) is greatly shortened (Fig. 13). We have not had such a patient who has reached adulthood. As a

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Fig. 13.—E. H., male aged eight years when seen in 1946. There had been incontinence and recurrent infection since birth as result of posterior urethral valves. PSP excretion 34 per cent in two hours; NPN 75 mg. per 100 cc. Bilateral nephrostomy was done. There was progressive diminution of renal function with recurrent infection and episodes of severe uremia. The patient died three years after operation. (A) Nephrostograms immediately after operation, and (B) two years later.

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Matthews, Kirkman, and Bacon in 1947 described a series of renal changes observed in the golden hamster following the prolonged administration of diethylstilbestrol and sesame oil. In male hamsters the changes seemed to be toward the formation of potentially malignant tumors, whereas in female hamsters the changes tended toward glomerulonephritis. In 1950, Kirkman and Bacon published data on the production of "malignant adenomas" of the kidney in male hamsters chronically treated with diethylstilbestrol. No lymph or blood-borne metastases were observed, but the tumors did metastasize by implantation throughout the abdominal cavity. Such growth did not develop in female animals similarly treated, or in male animals receiving cholesterol and diethylstilbestrol in the ratio of 4:1, or in any castrated male. The tumor cells did not contain any doubly refractive lipid, a point of note in view of the lipid-rich character of many human renal adenocarcinomas.

Experimental work has thus far provided no information of practical value to the problem of human renal cancer. However, attention has been called to the possibility of a role of steroid hormones in the genesis of human renal adenocarcinoma by the work of Kirkman and Bacon in hamsters. In this regard the following clinical and pathologic observations on patients with renal adenocarcinoma are of interest:

(1) The maximal incidence of human renal adenocarcinoma is in the sixth decade. The age incidence data are based on the age of patients at the time of diagnosis and by no means indicate the time of onset of the neoplasm. Even allowing for a difference of 10 or more years, however, between the age at the time of onset of the cancer and the age at the time of diagnosis, it is evident that most renal adenocarcinomas develop during a period of diminishing testicular androgen production in the male and diminishing ovarian estrogen production in the female.

(2) The sex incidence of human renal adenocarcinoma indicates a preferential occurrence in males at a ratio of approximately 7:3.

(3) Leary studied more than 300 miniature human renal tumors and concluded that crystalline ester cholesterol was a probable dominant factor in the growth of these neoplasms. He found that crystalline ester cholesterol was present in the renal epithelium before the new growth appeared, that the focal points of the early growth were limited to the areas in which cholesterol esters had been deposited, that there was a progressive increase in the quantity of cholesterol esters in the tumor as the latter increased in size, and that the disappearance of the cholesterol esters from the growing neoplasm was followed by cessation of growth.

(4) Although a small number of patients with inoperable and/or metastatic renal adenocarcinoma has been treated at Memorial Hospital with estrogenic and/or androgenic steroids, no objective evidence of any effect on the tumors has yet been observed.

The meager clinical and experimental evidence thus far available does no more than suggest a possible role of steroids in the growth of human renal adeno-carcinon

Renal Neoplasms

WILLET F. WHITMORE, JR., M.D.

RENAL NEOPLASMS occur with a frequency and range of clinical manifestations sufficient to warrant the interest of every clinician. The intent of this chapter is to summarize the pertinent clinical data regarding this group of neoplasms, to review briefly the methods of diagnosis, and to indicate and attempt to rationalize some recent therapeutic trends. Comments on pathology are limited to the minimum necessary for characterization of each tumor and for an understanding of its place in the classification.

GENERAL INCIDENCE

Renal cancers constitute 1.3 per cent of all neoplasms. Their frequency is slightly greater in males (1.7 per cent) than in females (1.0 per cent). In the male genito-urinary tract 9.7 per cent of all cancers are of renal origin, cancers of the prostate and bladder being, respectively, first and second in frequency. In the male and female urinary tracts renal cancers make up, respectively, 27 per cent and 35 per cent of the malignant neoplasms (Macdonald). During the four year period 1947-1950, malignant renal tumors constituted 0.779 per cent of all cancers at the Memorial Hospital (New York).

ANIMAL STUDIES CONCERNING RENAL NEOPLASMS

A growth histologically similar to the human Wilms tumor has been described in a variety of domestic and laboratory animals. Such a tumor is common in swine and also occurs in cattle (Feldman). A transplantable embryonal nephroma in rabbits has been studied by Greene and by Polson, and Mathews has found a similar lesion in chickens. Recently Olcott has described the occurrence of a spontaneous transplantable nephroblastoma in the rat.

Tumors histologically similar to human renal adenomas or adenocarcinomas have also been found in animals. Lucké has described the spontaneous occurrence of circumscribed adenomas or adenocarcinomas in the kidneys of the leopard frog, *Rana pipiens Schreber*, with an incidence as high as 2 per cent in both sexes. King and Nigrelli investigated the occurrence of glycerophosphatases in the normal and tumorous kidneys of such frogs and demonstrated histochemically the presence of a strong alkaline glycerophosphatase reaction in the proximal tubules of the normal kidney which was absent not only in the tumor cells of the neoplastic kidney but also in the adjacent nontumorous portions of the kidney.

(3) Sarcomas
(4) Endometriosis

VI. Pararenal Tumors
(1) Dermoid cysts and teratomas

VII. Tumors of "Rest" Origin
(1) From adrenal rests–hypernephroma
(2) Chondral and osseous rests

TUMORS OF THE NONEPITHELIAL TISSUES

This group includes benign and malignant nonepithelial tumors occurring within the confines of Gerota's fascia. It thus includes some tumors which are, strictly speaking, perirenal rather than renal neoplasms.

Benign Tumors. (1) Fibroma: Fibromas of the kidney are an occasional incidental finding at autopsy but only rarely reach a size sufficient to produce symptoms. The fibromas found incidentally at autopsy are usually small, frequently multiple, and occasionally bilateral, and occur either in the medullary pyramids or in the cortex, usually just beneath the capsule (Allen; Bell; Mackenzie). Mackenzie in 1936 could find only 15 clinical instances of pure fibroma in the literature.

Many of the clinical neoplasms reported as fibromas contain varying admixtures of other elements which warrant their inclusion in the benign mixed tumor group. Gordon-Taylor reported the clinical occurrence of a fibroma weighing 22 pounds and containing glandular elements presumed to represent remnants of renal tubules. Such tubular elements are often found in the incidental medullary fibromas encountered at autopsy (Allen; Bell) suggesting a possible hamartial origin for these tumors. The increasing frequency of fibromas with age in autopsies, however, is cited as evidence of their true neoplastic nature (Zangemeister). Fibromas of the kidney present no distinctive clinical features. That some of these tumors may reach a considerable size is evidenced by the report by Rush and Rush of the removal of a 13 pound fibroma from a 21 year old woman. Such tumors have been successfully treated by nephrectomy.

(2) Lipoma: True lipoma of the kidney may be either intrarenal or perirenal and must be distinguished from hypertrophy of the perirenal fat and from replacement lipomatosis.

The distinction between true perirenal lipoma and hypertrophy of the fatty capsule may be difficult. The latter is usually bilateral and is usually, although not invariably, associated with obesity.

Bell defines lipomatosis of the kidney as the replacement of the renal area by adipose tissue. Certain cases of atrophy or destruction of the renal parenchyma show a deposition of fat within the confines of the renal capsule sufficient to cause an over-all enlargement of the organ and, occasionally, a concomitant increase in perirenal fat. The intrarenal fat deposition is commonly considered to be a result of hyperplasia of the fat of the renal sinus but others (Farrow, Gross, Tannhauser, and Andrews) believe that the fat replacement represents the end stage in the life history of a lipoid granuloma. These authors point out that, contrary to the observations of others, the demarcation of the fatty tissue from the diseased kidney is not sharp.

CLASSIFICATION

The classification employed in this discussion is indicated in Table I. No attempt has been made to review the many controversial aspects of pathogenesis and classification to which so much of the literature on renal neoplasms is devoted.

TABLE I

CLASSIFICATION OF RENAL NEOPLASMS

I. Tumors of the Nonepithelial Tissues
  A. Benign Tumors
    (1) Fibroma
    (2) Lipoma
      (a) perirenal
      (b) intrarenal
    (3) Hemangioma
    (4) Myoma
      (a) leiomyoma
      (b) rhabdomyoma
    (5) Mixed tumors (composed of combinations of the above elements)
    (6) Lymphangioma
    (7) Renal tumors associated with tuberous sclerosis
    (8) Osteoma
  B. Malignant tumors
    (1) Sarcoma (various types)
    (2) Liposarcoma
    (3) Osteogenic sarcoma

II. Tumors of the parenchymal epithelium
  A. Benign tumors
    Adenoma
  B. Malignant tumors
    Renal cell carcinoma or renal adenocarcinoma

III. Tumors of the Epithelium of the Renal Pelvis
  A. Benign Tumors
    (1) Papilloma
  B. Malignant Tumors
    (1) Papillary transitional cell, epidermoid, or squamous carcinoma
    (2) Nonpapillary transitional cell, epidermoid, or squamous carcinoma
    (3) Mucous adenocarcinoma

IV. Embryonal Tumors
  (1) Embryonal tumors of adults
  (2) Embryonal tumors of children

V. Secondary Tumors of the Kidney
  A. Involving the Kidney by Direct Extension
    (1) By extension from a retroperitoneal node metastasis from a primary tumor elsewhere
    (2) By extension from a retroperitoneal viscus
    (3) By extension from an intraperitoneal viscus
    (4) By extension from a pararenal tumor
  B. Involving the Kidney by Metastasis
    (1) Lymphomas
    (2) Carcinomas

presence of an abdominal mass, a finding noted in 41 of the 42 cases. The abdominal enlargement may be symmetrical owing to the fluidity of the fat at body temperature. On pyelography marked renal and/or uretral displacement is the most striking finding, but actual deformities within the pyelogram are rare (Crabtree; Pfeiffer and Gandin). Differential diagnosis usually rests between abdominal carcinomatosis, ascites, pancreatic cyst, pregnancy, and ovarian carcinoma. The diagnosis is usually made at operation or at autopsy. In the 42 cases of Pemberton and McCaughan the diagnosis of retroperitoneal tumor was suggested in only 5 instances.

The treatment is surgical excision of the tumor, usually with the adjacent kidney. Since the gross distinction between lipoma and liposarcoma is difficult and since there is a strong tendency to recurrence and for malignant degeneration even in apparently benign lipomas, it seems wisest to attempt a complete excision of the tumor with the adjacent kidney at the initial operation. Technical difficulties in the complete removal of these tumors may be considerable owing to their tremendous size and to their tendency to fragment into lobules of fat on handling.

In the 42 cases reported by Pemberton and McCaughan, complete removal of the tumor was accomplished in only 21. Thirty-five patients had single tumors while 7 patients had multiple tumors, creating a total of 61 tumors, 44 of which were benign and 17 of which were malignant. Of the 42 patients, 8 were living and well for periods ranging from nine months to four years, 7 were lost from follow-up, 8 died postoperatively, 17 apparently died of recurrence, and 2 were living with recurrent disease. The operative mortality was 19 per cent. Although these growths tend to recur locally, there is little tendency for distant metastasis.

(b) Intrarenal lipoma. Intrarenal lipomas are fatty tumors developing within the renal parenchyma. Small lipomas occur as cortical or subcapsular fatty nodules in about 1 per cent of all autopsies, but only 14 instances of clinically occurring intrarenal lipoma have been reported (Robertson and Hand). The majority of the latter have occurred in middle-aged females. Twelve of the 14 neoplasms assembled by Robertson and Hand contained varying amounts of fibrous tissue, smooth muscle, epithelial elements, and blood vessels, in addition to fat, suggesting that such tumors may be properly classed as hamartomas.

Dull or colicky pain was recorded as a symptom in almost all of the 14 clinical cases and hematuria occurred in 3. These tumors are more apt to cause hematuria and pyelographic deformity than are perirenal lipomas. Most of the reported tumors were of fairly large size and in some cases a mass was palpable. Only 2 of the 14 cases had normal pyelograms (O'Heeron). Nephrectomy was performed in 13 cases and in the remaining case (Pemberton and McCaughan) the tumor was enucleated and the kidney saved. Follow-up data in the few cases reported does not permit any estimate of the prognosis. According to Lower and Belcher, these tumors are prone to recur in progressively more malignant form.

(3) Hemangioma: Although renal angioma is a rare and benign lesion, it may call for immediate and relatively radical treatment. Ewing defines angioma as a tumor composed of newly formed vessels, the distinction between hemangioma and lymphangioma depending on whether the tissue of origin is a blood or a lymphatic vessel.

Although Hamm and de Veer found lipomatosis only in obese individuals, Farrow et al. did not consider general obesity a factor since half of their patients were of average or slight build. The highest incidence is in middle-aged individuals. No instance of malignant change in lipomatosis has been reported. Although the condition is usually unilateral, instances of bilaterality are recorded. Simril and Rose could find no instance in which a preoperative diagnosis of lipomatosis had been correctly made, but report a case in which the correct diagnosis was suggested. Since lipomatosis develops in the wake of long-standing unilateral or bilateral renal disease, a history thereof is helpful in suggesting the possibility of such a diagnosis. The presence of pyuria, calculus, reduced or absent renal function, and filling defects in the renal pelvis completes the clinical picture—a picture which may closely simulate that of carcinoma of the renal pelvis. Examination of a stained smear of the urinary sediment (Papanicolaou and Marshall) should permit distinction between these two entities in the great majority of cases.

The practical importance of accurate differential diagnosis between lipomatosis and carcinoma of the renal pelvis is considerable. Although nephrectomy is indicated, as a rule, in either case, the surgical approach in carcinoma of the renal pelvis is radically different from that in lipomatosis.

(a) Perirenal lipoma. This term includes those benign fatty tumors arising within the confines of Gerota's fascia but extrinsic to the parenchyma of the kidney. Although all perirenal lipomas are retroperitoneal lipomas, the converse is not true. According to Pfeiffer and Gandin, perirenal lipomas constitute 35 per cent of retroperitoneal lipomas. Howard and Suby, in discussing this subject in 1938, stated that well over 200 cases had been reported. Pfeiffer and Gandin report a single case representing the first instance in 42,000 hospital admissions and cite Lubarsch as finding only one case in 40,000 autopsies.

The majority of cases have occurred in the age range of 40 to 60 years, but a case has been reported in an infant of 15 days (Pfeiffer and Gandin). Pemberton and McCaughan in 1933 found 314 retroperitoneal tumors of which 42 were classed as retroperitoneal lipomas. Their series included 40 extrarenal and 2 intrarenal lipomas. The average age in 42 cases was 49.3 years, with a range from 28 to 68 years. Nineteen of the patients were males and 23 females. Von Wahlendorf found 72 per cent of 165 cases and Adamis 70 per cent of 113 cases, to be females.

Many of the neoplasms reported as lipomas contain one or more other tissues, usually fibrous and myxomatous components. In Von Wahlendorf's series 46 per cent of the tumors were pure lipomas and 54 per cent of mixed type. Some of the lipomas show pathologic and clinical evidence of malignant change, presumably illustrating the development of liposarcoma in a benign lipoma.

Perirenal lipomas may grow to an enormous size and the possibility of this tumor should be considered in the differential diagnosis of any large abdominal mass. The majority of patients have abdominal enlargement or a mass as the presenting complaint. In the series of 42 cases presented by Pemberton and McCaughan, complaint of abdominal enlargement or a mass was present in 28, pain in 20, dyspepsia in 11, and weight loss in 11. Fever, hematuria, and urinary symptoms are rare manifestations. The most striking physical abnormality is the

hematuria is obtained. Pain was noted in 15 of the 36 cases reviewed by Riley and Swan and is usually colicky because of the passage of blood clots down the ureter. A palpable mass has been reported in only one case (Szecsey and Flesch). Anemia due to prolonged bleeding may be a feature.

The correct diagnosis is rarely made preoperatively, although Dean and McCarthy did so in a patient with hematuria who had multiple hemangiomas of the skin. The diagnosis is suggested by the following features (Lazarus and Marks): A long history of hematuria without weight loss, frequency, or dysuria; prolonged hematuria from one kidney without change in size of the kidney; repeatedly negative tuberculosis studies; the finding of a normal kidney at the time of exploration. Although pyelographic changes are often found, the filling defects seen are not characteristic and are usually attributed to causes other than the existing angioma.

Mackey points out that lesions of the renal pelvis bleed most, those of the pyramids somewhat less, and those of the cortex rarely. McKay, Baird, and Lynch found that in 18 cases of varix all patients required emergency nephrectomy for uncontrolled bleeding, that no pyelographic abnormalities were noted, and that in all but one case the lesion was minute. In 54 cases of angioma, however, the lesion usually caused some defect on the pyelogram. Thirty-three of 37 patients with angioma who were actively treated had nephrectomy and one had a papillectomy.

It is apparent that the chief barrier to more successful conservative treatment of these lesions is the inability to make a correct preoperative diagnosis. Many kidneys containing angiomas have been sacrificed on the basis of a presumptive diagnosis of malignant neoplasm. Paletz and Sewell have recently reported an interesting case of apparent bilateral renal angioma. The patient was a 21 year old Negro who had a right nephrectomy because of persistent hematuria. Examination of the removed kidney revealed multiple diffuse angiomas. The patient subsequently began to bleed from the left kidney and this bleeding was apparently successfully treated by irradiation.

(4) Myoma: True myomas of the kidney are extremely rare but leiomyoma is more common than rhabdomyoma.

(a) Leiomyoma. Three groups of renal leiomyomas can be distinguished (Zuckerman, Kershner, Laytner, and Hirschl):

(i) small, frequently multiple myomas several millimeters in diameter found incidentally beneath the capsule in the superficial cortex of the kidney at autopsy

(ii) large solitary growths occurring during life and causing symptoms

(iii) myomas which appear to have undergone definite malignant change

Bell states that renal leiomyoma is a fairly common incidental finding at autopsy. Gordon, Kimmelstiel, and Cabell assembled 29 cases of leiomyoma in 1939. Eight of these were incidental autopsy findings, 6 occurring in females and 2 in males. In 17 cases the tumor reached sufficient size to cause symptoms and to require surgical exploration. The majority of the latter occurred in females.

Although Watson and McCarthy considered angiomas to be the largest single group of neoplasms in children, the renal occurrence of these tumors is rare. Bell could find only one instance in 30,000 autopsies. Kidd could find no cases in 2,500 personally performed autopsies in which renal angioma was especially sought. In a review of the literature in 1949, McKay, Baird, and Lynch found 54 cases of renal angioma and 18 cases of renal varix.

In 70 cases of renal angioma (including varix) reviewed by Lazarus and Marks, in which the sex was mentioned, 25 were females and 34 were males. The majority of cases occurred in the third and fourth decades with ages ranging from four days to 66 years. Fifty-five per cent of the cases in which the age was stated were between 21 and 40 years of age and 70 per cent were less than 40 years of age.

In the majority of cases the lesion is single and unilateral, but multiplicity and apparent bilaterality (Paletz and Sewell) have been reported. The tumors have varied from a few millimeters in diameter to a mass occupying one third of the kidney (Gile). Of the cases reviewed by Lazarus and Marks, 86.9 per cent had single and 13.1 per cent multiple tumors.

White and Braunstein classify the renal vascular tumors, excluding telangiectasis and varix, into benign forms which include the capillary hemangioma, plexiform hemangioma, and cavernous hemangioma, and malignant forms such as hemangiosarcoma and hemangioblastoma. The capillary form presents commonly as a small papillomatous lesion projecting into the calyces or pelvis, whereas the plexiform and cavernous types and malignant lesions may be found anywhere, but usually under the epithelial lining of the calyces or pelvis. Dukes doubts that renal angioma is a neoplasm or even a vascular malformation, but suggests rather that it represents vascular reparative tissue resulting from trauma or infection. Jacobs and Rosenberg have called for a distinction between true telangiectasis and true angioma, pointing out that the former is vascular enlargement resulting from dilatation and capillary proliferation, whereas the latter is angioblastic, constitutes a true neoplasm, and usually shows only one afferent and one efferent vessel. Jenkins and Drennan, however, feel that the difference between telangiectasis and angioma is one of degree rather than of kind. However justified, on pathologic grounds, the distinction between angioma and telangiectasis or varix may be, the case reports and reviews in the literature rarely permit a sharp line of distinction to be drawn between the two conditions. Borst has suggested that renal angioma is a form of hamartoma. The hemangioblastoma occurring in a case of von Hippel's disease (Melicow) lends some support to this thesis if one accepts von Hippel's disease (retinal angiomatosis) as an illustration of hamartiosis (Moolten). These tumors may occur anywhere in the kidney but the tip of the papilla is the most common site. In the latter position they are usually small although lesions of the calyx and pelvis often reach considerable size before breaking into the pelvis.

Although most benign renal growths produce symptoms by virtue of their size, hemangioma of the kidney is an exception. Hematuria, occasionally massive and usually intermittent, is the first, the most common, and the only symptom in the majority of cases. It was present in 95 per cent of the cases reviewed by Lazarus and Marks. Occasionally a prolonged history of intermittent

of patients in Henthorne's series had some form of chronic inflammatory or obstructive renal disease, the possibility of an acquired lymphangiectasis was considered strong. The cysts occurred as multiloculated confluent masses about the renal pelvis and in the renal hilus. In only one of 20 cases was the size of the lesion considered of possible clinical importance.

Kretschmer and Hibbs reviewed the literature on retroperitoneal lymphangioma in 1931 and were able to find only 4 cases to which they added one. Four of the tumors occurred in males, the other in a female. The ages of the 5 patients were four, five, 40, 58, and 59 years. The symptoms were those of any retroperitoneal tumor. Four of the patients had a mass and 3 had pain. The diagnosis was not made until operation in any of the cases, although the authors' case showed pyelographic deformity suggestive of renal tumor. The outcome was good in 4 of the 5 cases. In only one case was the neoplasm actually attached to the kidney although it was adjacent to the kidney in at least two other instances reported in the literature.

Wynn-Williams and Morgan report a case of polypoid lymphangioma of the kidney in a 33 year old woman whose retrograde pyelogram showed a distorted pelvis, suggesting a tumor of the pelvis or parenchyma. Pulaski reports a case of unilateral pyelonephritis presumably resulting from compression of the left renal pedicle by a cavernous lymphangioma. The patient had hypertension and ultimately died from intracerebral hemorrhage.

According to Ewing such retroperitoneal lymphangiomas represent true neoplasms and consist of multilocular, cavernous, and cystic masses originating along the spinal column and ramifying retroperitoneally. Microscopically the tumor is composed of lymph vessels of varying size. The pathogenesis of these lesions is uncertain.

(7) Renal Tumors Associated with Tuberous Sclerosis: Because of the frequent association of renal growths with tuberous sclerosis, some characterization of the latter entity is warranted. According to Moolten 2 or more of the following criteria are necessary for the diagnosis of the tuberous sclerosis complex: mental retardation, epilepsy, adenoma sebaceum, phacoma of the retina, multiple mixed tumors of the kidney, and a familial history. More than half of the patients warranting the diagnosis of tuberous sclerosis will have renal tumors, usually occurring as incidental autopsy findings. Occasionally the bulk and multiplicity of these lesions may cause uremia or give the pyelographic picture of renal polycystic disease.

The tumors are commonly considered hamartomas and therefore not neoplasms in a strict sense. They may occur singly or as multiple nodules in the cortex. The atypical cytology and architecture of the lesions suggest neoplasia and account for the terms angiofibroliposarcoma, fibroliposarcoma, fibrolipomyo-angioma, fibrolipomyo-angiosarcoma, etc. Occasionally true renal neoplasms do occur in cases of tuberous sclerosis. A few instances of tuberous sclerosis associated with renal adenocarcinoma or adenomyosarcoma have been reported.

Moolten points out that isolated hamartomas of the kidney may occur independently of the tuberous sclerosis complex and cites the medullary fibroma as an illustration. The solitary, benign mixed tumors of the cortex which are commonly classified according to the dominant tissue element (hemangioma, lipoma,

In 8 of the 17 the tumors were pathologically malignant. The age range in the clinical instances varied from 15 to 71 years.

The histogenesis of this neoplasm is uncertain. Although smooth muscle is normally found in the renal pelvis and calyces and in the renal capsule, it is absent from the parenchyma except in the walls of the blood vessels. It has been suggested that these tumors are choristomas or hamartomas or that they arise from smooth muscle in the capsule, calyces, or blood vessels. Leiomyomas have a tendency to form large arteries, a rather unique pathologic feature.

The tumors are usually slow-growing, circumscribed masses which cause symptoms because of their size. Mass and pain are the most common presenting complaints, although hematuria occurs rarely. Of the 17 surgical cases referred to above, 13 had pain, 9 had a mass, 2 had fever, and 2 had hematuria. Pyelographic studies usually show changes suggestive of renal tumor. The small number of cases, the often unsatisfactory pathologic data, and the incomplete follow-up periods make an accurate estimate of prognosis impossible.

(b) Rhabdomyoma. According to Ewing, tumors containing striated muscle occur more frequently in the kidney than in any other organ. Most, if not all, neoplasms of the kidney containing skeletal muscle belong in the embryonal group of renal growths. Constance has reported the occurrence of bilateral flank masses in a one year old infant in whom bilateral tumors consisting primarily of striated muscle were found. Such a tumor can be properly considered a variant of the Wilms embryoma.

(5) Mixed Tumors: Mixed tumors of the kidney are composed of more than one tissue element and are not to be confused with the mixed embryonal tumors which will be considered in a later section. Most of the neoplasms already discussed occur in a relatively rather than absolutely pure form and commonly contain tissues other than the one from which they derive their name. Isolated instances of a wide variety of such mixed tumors of the kidney have been reported, including fibrolipomyoma, lipomyoma, lipofibroma, myxolipoma, lipomyo-angioma, and many other combinations. Although nonepithelial elements predominate, epithelial elements occasionally occur as in the adenofibroma reported by Gordon-Taylor. That some or all of these tumors may be hamartomas has been suggested. The symptoms produced by these growths are usually those due to size and pressure. Mass and pain are common. Hematuria is relatively uncommon. The usual treatment in the reported cases has been nephrectomy.

(6) Lymphangioma: True perirenal lymphangioma is an extremely rare tumor. Solitary peripelvic lymphatic cysts and multilocular lymphatic cysts must be distinguished from true lymphangioma. Peripelvic lymphatic cysts are rare, generally small, and usually incidental findings at autopsy (Scholl). On the rare occasions when such cysts reach large size, there may be pain and pyelographic distortion. Scholl has reported 2 cases in which the pressure of a peripelvic cyst on the renal vessels presumably caused hypertension which was relieved following nephrectomy.

Multiloculated lymphatic cysts have been discussed by Henthorne who found such cysts in 1.28 per cent of 1,175 autopsies in patients between 17 and 71 years of age. The average age incidence was 60.5 years. They occur about four times as commonly in males as in females. In view of the fact that the majority

nodule in the liver. There was no evidence of a lymphosarcoma elsewhere in the body.

Renal sarcomas are generally large, the average weight being 1262 gm. and the average size being 15 × 14 × 12 cm. (Judd and Donald). In only 2 of 20 cases was a capsular origin suggested for the tumor, the others apparently arising within the renal parenchyma. Among 35 cases of renal sarcoma, 40 per cent showed gross invasion of the renal vein and 31 per cent had gross invasion of the renal pelvis (Weisel, Dockerty, and Priestley). The tumors were generally encapsulated, but in one third of the cases there was invasion either of the kidney or of the surrounding tissues.

Clinically these tumors exhibit no features which distinguish them from renal adenocarcinomas. In 35 patients the average duration of symptoms was 10 months (Weisel, Dockerty, and Priestley). Thirty-one of the patients had a mass and pain either singly or as combined symptoms, and 9 had gross hematuria. Twenty-eight patients had a palpable mass and 4 had fever. The pyelographic findings show no significant differences from those of the more common forms of parenchymal renal cancer. The roentgenographic findings suggested renal tumor in 17 of 35 cases (Weisel, Dockerty, and Priestley).

Nephrectomy was accomplished in 31 of 35 patients while 4 patients had only laparotomy and biopsy (Weisel, Dockerty, and Priestley). According to Powell and Clark, a 10 per cent five year survival can be anticipated. Weisel, Dockerty, and Priestley also estimate the five year salvage rate at 10 per cent. In the majority of cases there is recurrence within six months and death within 10 months postoperatively. The operative mortality has been between 15 and 20 per cent in the cases subjected to nephrectomy.

(2) Liposarcoma: Malignant retroperitoneal fatty tumors include some of the most massive growths ever reported. Hirsch and Wells report a 69 pound liposarcoma surrounding but not invading the kidney. The great majority of these neoplasms are actually perirenal rather than intrarenal in origin. Stout has pointed out the predilection of liposarcoma for the perirenal area and the fact that this tumor is much less common than lipoma. Liposarcoma apparently arising within the kidney is rare. Thirteen apparent instances have been reported, only 5 of which were not associated with tuberous sclerosis (Newman and Reed). Considering all forms of liposarcoma, the sex incidence is approximately equal and the majority of cases occur beyond the age of 40 years with a mean age of 53 years (Stout). Cases in children have been reported.

The growth rate may vary markedly in different cases. The tumor may continue to grow even though the host is becoming emaciated, but no qualitative difference between the tumor fat and the normal fat has been detected. The presence of a huge abdominal mass is the most striking clinical feature. Pain, fever, weight loss, anorexia, and pressure symptoms make up the remainder of the clinical picture. Complete surgical excision offers the only prospect of cure. Although these tumors are often slow-growing, they tend to recur locally following removal. Metastases rarely occur.

(3) Osteogenic Sarcoma: Extraskeletal ossifying tumors are rare, and osteogenic sarcoma occurring as a primary tumor in the kidney is most unusual. In 1936 Haining and Poole reported the case of a 76 year old man with an

myoma, etc.) are considered by Moolten to have a possible hamartial origin. The same author believes Lindau's disease to be a form of hamartiosis of vascular type, characterized by retinal angiomatosis (von Hippel's disease), cerebellar angiomas, cysts of the liver, pancreas, and kidney, and angiomas, adenomas, or adenocarcinomas of the kidney. Single large renal tumors occur rarely in patients with tuberous sclerosis but multiple bilateral tumors are common, occasionally associated with renal cysts and other anomalies (Fish and McLaughlin). The varying growth rates of different lesions in the same individual explain how a patient with tuberous sclerosis with less active brain lesions can reach adult life with little or no neurologic signs or symptoms and at that time manifest a renal neoplasm. Fish and McLaughlin report a case in the latter category. Greene and Rosenthal have reported the occurrence of multiple "hypernephromas" of the kidney in association with Lindau's disease.

(8) Osteoma: True pararenal osteoma is an extremely rare tumor and must be distinguished from the metaplastic ossification or chondrification which occurs occasionally in perirenal lipomas (Allen), and also from the occasional bone formation found within a pararenal teratoma. Kretschmer has reported a case of true pararenal osteoma.

Malignant Tumors. (1) Sarcoma: According to Armstrong, less than 100 cases of all varieties of renal sarcoma appear in the literature, and of these approximately one-third are apparently fibrosarcomas. Of 570 patients who had operations for malignant renal tumors, 28 were found to have sarcomas, 20 (3.5 per cent) of which were proved microscopically to arise from the kidney itself (Judd and Donald). According to Powell and Clark, renal sarcoma constitutes 2 to 3 per cent of primary renal tumors. Renal sarcoma occurred once in 30,000 admissions and Wilms's tumor approximately once in 25,000 admissions at the Mayo Clinic (Weisel, Dockerty, and Priestley). The same authors found renal adenocarcinoma to be about 20 times as common and epithelial renal pelvis tumors approximately four times as common as renal sarcoma.

The sex incidence is equal. Of 35 cases, 19 occurred in males and 16 in females (Weisel, Dockerty, and Priestley). The ages ranged from two and one half to 76 years, with the peak incidence in the early part of the sixth decade. In the review by Mintz, 55 per cent of the patients fell within the age range of 40 to 60 years.

Much of the confusion regarding renal sarcomas is due to failure to distinguish these growths from anaplastic and undifferentiated carcinomas, from lymphomas and from tumors of the embryonal group. In the cases reported by Judd and Donald, 6 were fibrosarcomas, 6 were sarcomas of undiagnosed type, 3 were spindle cell sarcomas, and there was one of each of the following: round cell sarcoma, liposarcoma, myxosarcoma, fibromyxosarcoma, and mixed cell sarcoma. In a review of 93 cases of adult renal sarcoma, Mintz found 23 spindle cell sarcomas, 16 unclassified sarcomas, 12 fibrosarcomas, 11 embryonal mixed sarcomas, 6 leiomyosarcomas, and smaller numbers of various other types. There is no authenticated instance of a lymphoma primary in the kidney. However, recently Davis and Olivetti have reported a 67 year old man who died of uremia and in whom autopsy revealed diffuse bilateral lymphomatous infiltration of both kidneys, both adrenals, and the adjacent fat, and a single small lymphomatous

much maligned term "hypernephroma." The latter was employed by Birch-Hirschfeld to designate the tumor which Grawitz considered to originate from adrenal rests, but which is now generally conceded to arise from the epithelium of the renal parenchyma. The term "hypernephroma" properly should be reserved for those rare tumors of true adrenal rest origin.

Renal adenocarcinoma makes up approximately 80 per cent of all renal tumors; 502 (78.2 per cent) of 642 malignant renal neoplasms were of this type (Priestley). Melicow found 167 (83.9 per cent) cases of renal adenocarcinoma in 199 renal tumors. The highest incidence occurs in the decade from 50 to 60 years. In 367 cases the average age was 51.76 years (Judd and Hand). Approximately 80 per cent of all cases occur in the fifth, sixth, and seventh decades. The majority of authors indicate a definite predominance of males over females for this neoplasm, the ratio varying between 6:4 and 7:3.

Renal adenocarcinoma has been reported in association with renal anomalies, polycystic disease of the kidneys, renal calculi, and other types of renal neoplasms, but such occurrence can be considered no more than coincidental. Occasional instances of bilaterality have been reported. Hyman and Leiter report 4 cases of amyloid disease associated with renal adenocarcinoma and suggest that the amyloidosis may have been due to the long existence of a type of neoplasm which is prone to show degenerative changes.

Much time and effort have been expended in attempts to subdivide renal adenocarcinomas into different pathologic types on the basis of tumor pattern and cytology, and on the basis of presumed differences in pathogenesis. It has become increasingly evident, however, that different portions of the same neoplasm may show wide variations in cytologic and structural characteristics, and that such subdivisions are arbitrary and artificial (Foot and Humphreys; Foot, Humphreys, and Whitmore). It, therefore, seems most reasonable to employ the term "renal adenocarcinoma" or "renal cell carcinoma" to characterize all tumors within the group, with the realization that the cytologic and structural characteristics of any given tumor have significant bearing on the prognosis (Hand and Broders; Foot, Humphreys, and Whitmore).

Renal adenocarcinoma may occupy any portion of either kidney. Although the tumor is characteristically large, a wide range in size is possible. The gross and microscopic distinction between benign adenoma and malignant adenocarcinoma, as has been previously mentioned, may be exceedingly difficult, but clinically adenocarcinoma is far more frequent.

With increasing experience it has become more and more evident that there is no single symptom or symptom-complex which is characteristic of renal adenocarcinoma. Even the classic triad of pain, hematuria, and tumor may occur in other conditions. When this triad does occur in the presence of renal tumor, it usually indicates a hopeless prognosis. In 100 consecutive patients with renal adenocarcinoma, 31 manifested this triad and all were inoperable (Herger and Sauer).

Of the urinary symptoms associated with renal neoplasms, hematuria is by all odds the most dramatic and the most characteristic. It is the initial symptom in roughly 40 per cent of all patients and occurs at some time during the course of the illness in 70 to 80 per cent of all patients. It is usually intermittent and may

osteogenic sarcoma of the left kidney which had metastasized to the right kidney, to the liver, and to the bowel. Hamer and Wishard in 1948 presented a strikingly similar case. The patient was a 76 year old man with hematuria who was found to have an osteogenic sarcoma arising adjacent to the right kidney, invading the kidney, and metastasizing to bone.

Tumors of the Parenchymal Epithelium

Neoplasms of this group are by far the most common and, therefore, the most important of renal tumors.

Benign Tumors. (1) Adenoma: Adenomas are common incidental findings at autopsy and occasionally grow to a size sufficient to produce symptoms. The frequency of incidental renal adenomas has been variously reported as between 0.13 per cent and 3.7 per cent of all kidneys examined (Kozoll and Kirshbaum; Nurnberg; Newcomb), the incidence increasing progressively in the decades past middle life and paralleling the incidence of renal vascular disease. Cristol, McDonald, and Emmett found that incidental adenomas occur with greater frequency in kidneys containing renal adenocarcinoma than in noncancerous kidneys. They found an over-all incidence of 4.4 per cent incidental adenomas in patients with renal adenocarcinoma, 5.8 per cent in males and 1.3 per cent in females.

Fifty instances of clinically important adenomas have been reported (Cristol, Bothe, and Grotzinger). The age incidence of these neoplasms approximates that of renal adenocarcinoma. In 50 cases the age range was from 11 months to 81 years. The sex incidence in the clinical adenomas is equal, a feature which distinguishes them from renal adenocarcinomas.

The majority of incidental adenomas found at autopsy are small growths varying in size up to a few millimeters in diameter, usually occurring in sclerotic kidneys in association with cysts, and occasionally being multiple and bilateral. The gross distinction between a large adenoma and a renal adenocarcinoma may be difficult, and indeed the microscopic criteria of differentiation are not clear-cut. Bell distinguishes a papillary cystadenoma which may be solid or cystic and usually occurs in association with cysts and cortical scars in sclerotic kidneys, and a solid adenoma which occurs in the cortex of an otherwise normal kidney. He believes that the former rarely if ever develops into a malignant tumor, whereas the latter is arbitrarily considered malignant if its diameter exceeds 3 cm.

Clinically occurring adenomas show no important differences from renal adenocarcinoma as far as the clinical picture is concerned. Twenty-seven of the 50 cases had gross hematuria (Cristol, Bothe, and Grotzinger). The classic triad of pain, mass, and hematuria may also occur in renal adenoma. Pyelography usually reveals a deformity typical of parenchymal tumor of the kidney. The common treatment has been nephrectomy. Of the 50 patients 3 had large adenomas at autopsy, 43 had nephrectomy, 3 had local excision, and 1 had simple biopsy. There are no data on the prognosis of these tumors.

Malignant Tumors. Renal Adenocarcinoma: Carcinomas of the renal epithelium constitute by far the most common and most important group of renal neoplasms. The term "renal cell carcinoma" or " renal adenocarcinoma" is preferrred to the

and these metastases may cause the presenting symptoms in some cases. The lungs are the most common site of metastases, with the liver, lymph nodes, and bones being involved in about that order of frequency thereafter. Approximately 50 per cent of the metastases occur in the lungs. Occasionally, bizarre metastases to the skin, tonsil, larynx, thyroid, or vagina may be responsible for the presenting symptoms, and more commonly metastatic involvement of Virchow's node or of the upper humerus may be responsible for the initial complaints. More than one lobectomy or pneumonectomy has been carried out for a supposedly primary pulmonary tumor which ultimately proved to be a metastasis from a renal adenocarcinoma. Approximately one third of all patients with renal adenocarcinoma are deprived of any hope of surgical cure by virtue of the fact that metastases are present at the time of diagnosis. Of the patients without evidence of metastases, about 90 per cent have removable tumors (Priestley). The operative mortality for nephrectomy has fallen steadily during the past 20 years and is now in the vicinity of 1 per cent. The following factors have been shown to be associated with the prognosis of renal adenocarcinoma:

(1) The average duration of symptoms preoperatively and the average duration of life following nephrectomy, both in the living and the dead patients, are less for females than for males, suggesting that renal adenocarcinoma runs a more rapid course in women (Judd and Hand).

(2) The patients who survive longest following nephrectomy have their first symptoms at an earlier average age than those patients who obtain a poor result following nephrectomy (Judd and Hand).

(3) The average duration of symptoms preoperatively was longer in those patients who were explored and found to be inoperable than in those who were explored and had nephrectomy (Judd and Hand).

(4) The most favorable prognosis occurs in those patients whose only symptom preoperatively is hematuria (Herger and Sauer; Harvey). When the classic triad of pain, hematuria, and a mass is present, the neoplasm is always far advanced (Herger and Sauer). Such constitutional symptoms as fever, weakness, and weight loss do not mean a hopeless outlook and may disappear promptly with removal of the renal tumor.

(5) Forty per cent of patients with a presenting hemoglobin of 80 per cent or more survived 10 or more years, whereas only 20 per cent of patients with a hemoglobin of 60 per cent or less survived 10 or more years after operation. Similarly, patients with a leukocyte count of 6,500 or less did better than those with a higher count (Priestley).

(6) Calcification within a renal tumor is considered a favorable sign by some (Fetter; Braasch and Griffin; Goldstein and Abeshouse), and an unfavorable sign by others (Austen; Cahill and Melicow).

(7) Tumors occurring on the right side seem to be associated with a more favorable prognosis than do tumors occurring on the left side (Judd and Hand), presumably because of the fact that the lower position of the right kidney leads to earlier diagnosis.

(8) Strangely enough, upper pole tumors were associated with a greater life expectancy than were tumors of the lower pole or middle portion of the kidney.

(9) The weight of the tumor is an important factor in prognosis. Of patients

occur only once during the course of the illness. Although the bleeding is ordinarily painless, colicky pain may result from the passage of blood clots down the ureter. Hematuria of tumor origin is usually more severe than that from other causes and is usually unaccompanied by other urinary symptoms. The bleeding resulting from neoplasm may represent bleeding from the growth per se or from a passively congested kidney parenchyma adjacent to the tumor. There is nothing characteristic about either the duration or periodicity of the bleeding from a tumor.

Lumbar pain occurs in approximately 50 per cent of patients. The pain may be colicky because of the passage of blood clots, dull and aching, or of neuralgic type owing to tumor pressure on, or actual tumor invasion of, the ilioinguinal, iliohypogastric, genitofemoral, or subcostal nerves.

A varying proportion of patients complain of symptoms outside of the urinary tract. In 58 cases of renal neoplasm presenting 191 symptoms, 58 per cent of the symptoms were urologic, 18 per cent constitutional, 14 per cent gastro-intestinal, 5 per cent cardiorespiratory, 4 per cent neurologic, and 1 per cent skeletal (Nalle). Of the constitutional symptoms, weight loss was the most common and occurred in 60 of 100 consecutive cases while weakness and fatigability were present in 22 patients and fever in 9 (Cahill). Occasionally, constitutional symptoms may be the only manifestation of a renal tumor and, rarely, fever may be the first or only symptom and sign (McCague). The most common gastro-intestinal symptoms are nausea, vomiting, and constipation, and occasionally these may be the presenting or the only symptoms of a renal neoplasm.

The most striking physical finding is the presence of a mass which is palpable in 40 to 80 per cent and has been personally noted by the patient in 10 to 15 per cent of all cases. According to Harvey, 93 per cent of patients showed proteinuria, 77 per cent microscopic hematuria, and 59 per cent gross hematuria. Examination of the urinary sediment by the Papanicolaou technic may have supplemental value in the diagnosis of renal adenocarcinomas, but cells from this neoplasm may not appear in the urine, or, appearing, may offer considerable difficulty in differentiation from normal renal epithelial cells.

Calcification may be a helpful diagnostic feature in the diagnosis of renal tumors. *Cahill and Melicow reported small or large areas of calcification in* 15 per cent of 82 cases of renal adenocarcinoma. Austen observed calcification in 16.3 per cent of 98 malignant renal tumors. Intravenous and retrograde pyelography usually permit an accurate presumptive diagnosis.

There is no doubt that nephrectomy is the treatment of choice for renal adenocarcinoma. Although some such growths will diminish in size with irradiation, this reduction in bulk is due more to infarction from the effects of the therapy on the blood vessels than to direct effect on the tumor cells. Vermooten, on the basis of what he considers to be a definite difference betwen cortical and medullary renal adenocarcinomas, suggests that cortical tumors may, in some instances at least, be successfully treated by local excision with a 1 cm. margin of healthy kidney. This certainly represents a radical therapeutic although not a radical surgical approach.

Approximately one third of all patients with renal adenocarcinoma have metastases to distant structures when they are first seen (Cahill; Fetter; Nalle),

In Priestley's large series of renal adenocarcinomas, the five year survival rate was 38.4 per cent and the 10 year survival rate was 27.3 per cent, based on the number of traced patients who had had nephrectomy. Foot, Humphreys, and Whitmore found a 38 per cent five year survival in 85 determinate cases and a 22 per cent 10 year survival in 40 determinate cases of renal adenocarcinoma. The difference in the five and 10 year survival rates is a clear demonstration of the relatively slow growth of the majority of these tumors. Other evidence of this slow growth is furnished by the frequently long history of pain, abdominal mass, or intermittent hematuria obtained at the time of initial examination. Fetter has reported an instance of left nephrectomy for renal adenocarcinoma with renal vein tumor thrombosis at the time of operation, but without evident distant metastasis. Five years later the patient developed recurrence in the left scrotal veins and epididymis. These structures were removed and the patient was still living and well 13 years after nephrectomy. Snelling has cited 2 patients who developed local recurrences nine and 15 years after nephrectomy for renal adenocarcinoma and who died 12 and 16 years, respectively, after nephrectomy.

The peculiar clinical behavior of renal adenocarcinomas is further evidenced by the rare report of the spontaneous disappearance of apparent metastases following removal of the primary lesion. Such cases have been reported by Bumpus and by Mann. Barney and Churchill report a patient with renal adenocarcinoma and a solitary pulmonary metastasis who was treated by nephrectomy followed 15 months later by partial lobectomy and who has since survived over 12 years (Alexander and Haight). Such a result stimulates interest in a more radical approach to the problem of renal adenocarcinoma with an apparently solitary metastasis, particularly when the latter appears some years after the removal of the primary lesion. Certainly anyone who has seen a considerable number of patients with renal adenocarcinoma cannot fail to be impressed by the bizarre manifestations of this tumor and by the rare instances of prolonged survival even in the presence of widespread metastatic disease. Although local recurrence appears in about one third of the therapeutic failures following nephrectomy, the concomitant presence of metastases, usually in the lungs, liver, or bones, frequently constitutes a more pressing problem.

Several authors have called attention to a possible relationship between hypertension and renal tumors. Many more clinical observations must be made, however, before the presence of any direct causal relationship can be either affirmed or denied. In a clinical study of 57 patients with "hypernephroma" Bohn found 8 instances of renal and 15 of essential hypertension, but could establish no causal relationship between the neoplasm and the hypertension. Hypertension did not occur in patients with extensive unilateral or bilateral growths or in 3 patients with additional venous occlusion by tumor. Morlock and Horton were likewise unable to establish any definite relationship between renal neoplasm and hypertension in a survey of 491 cases.

with tumors weighing 500 gm. or less 46.5 per cent survived five or more years, whereas 24.6 per cent of patients with tumors of 1000 gm. or less survived five or more years after operation (Priestley).

(10) Extension of the tumor into the renal capsule, perirenal fat, hilar nodes, peritoneum, or adjacent viscera was generally associated with an unfavorable prognosis.

(11) Renal epithelial tumors show remarkable and unusual tendencies to advance via veins. Bonnecarrere has pointed out that slowing of the circulation, parietal injury of the vessel, and alteration of the blood constituents result in the formation of obliterant and progressive tumor thrombi which account for the multiple nodules of carcinoma occasionally seen within the same kidney.

Ney has pointed out that renal tumors are by far the most common cancer associated with tumor thrombosis of the inferior vena cava, and that such thrombosis is usually a direct extension from the renal vein. Most of the cases in which thrombosis of the inferior vena cava is associated with renal tumor have been on the right side, probably owing to the presence of a shorter renal vein on that side. In such patients, edema of one or both extremities is a common finding and survival for more than six months after signs of obstruction have developed is unusual. Renal vein thrombosis was accompanied by an absence of visualization of the kidney on intravenous pyelography in 8 of 16 cases (Beer). The presence of multiple large distended veins over the surface of the tumor is also suggestive of renal vein thrombosis. Venous thrombosis is usually associated with a poor prognosis, but does not necessarily mean a hopeless one.

(12) The pathologic features of the tumor are of major significance in prognosis (Hand and Broders; Priestley; Melicow; Foot, Humphreys, and Whitmore). When graded according to the method of Broders, Priestley found 73.3 per cent of grade I cases surviving three or more years *, whereas only 22.2 per cent of grade IV cases survived a similar period, and ten or more years after operation the corresponding survival rates were 47.6 per cent and 3.2 per cent, respectively.

Foot, Humphreys, and Whitmore found that a favorable pathologic picture was the most prominent common denominator in an analysis of nine 10 year survivals (22 per cent of 40 determinate † cases) following nephrectomy for renal adenocarcinoma. Tumors made up of clear cells with isometric nuclei, arranged in solid cords or in alveolar pattern with dense, coarse fibrous septa seemed to offer a better prognosis than tumors containing granular cells in papillary or tubular patterns with irregular thin septa. Cystic degeneration and hemorrhage seemed to be favorable factors of secondary importance in the prognosis. Cahill estimates the five year survival at 25 to 50 per cent for clear cell renal adenocarcinomas and 5 to 10 per cent for granular cell tumors.

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* Survival rates are based on the number of traced patients who had submitted to nephrectomy.

† The designation "determinate" excludes from the survival calculations patients who: (1) applied after treatment elsewhere and had no evidence of cancer on admission or thereafter; (2) patients who came for consultation only, without request for treatment; (3) patients who refused treatment; (4) patients who died within the indicated survival period (five or ten years) of other causes without recurrence of cancer; (5) patients lost track of within the indicated survival period without recurrence of cancer. The designation "determinate" includes operative deaths, however.

genesis has been widely discussed. Kutzmann found leukoplakia in 11.9 per cent of cases of squamous carcinoma of the renal pelvis. Leukoplakia of the renal pelvis is, therefore, regarded as a precancerous lesion, and, according to McCrea, should be treated by nephrectomy. Although chronic irritation, vitamin A deficiency, chemical irritation, and congenital rests have been invoked to explain the leukoplakia, the latter is sometimes unassociated with any of the considered etiologic factors. Of the 3 cases of mucous adenocarcinoma which have been reported, all have been associated with chronic renal infection and calculus (Ragins and Rolnick; Ackerman; Plaut).

In 74 patients with papillary growths involving the kidney and ureter or bladder, hematuria was present in over 95 per cent, pain in slightly over 50 per cent, a palpable tumor in about 15 per cent, and the classic triad of pain, tumor, and hematuria in 10 per cent (Kimball and Ferris). A palpable mass is less common in such patients than in those with renal adenocarcinoma and, when it does occur, is usually due to hydronephrosis occasioned by obstruction of the renal outlet by the neoplasm. Infection secondary to obstruction is far more common in tumors of the renal pelvis than in renal parenchymal lesions. The Papanicolaou smear of the urinary sediment is of considerable value in the differential diagnosis of malignant lesions of this group, but of little value in the benign papilloma. As might be anticipated, tumor cells are usually abundant in the urine in these cases, but the cytologic variation from normal is so slight with benign papilloma that a positive diagnosis cannot be made. Unless the ureter is completely blocked, a carcinoma of the renal pelvis or ureter usually provides good material for diagnosis by the Papanicolaou method. On pyleography a diagnosis of neoplasm of the renal pelvis was made in about two thirds of the cases while some form of obstructive nephropathy or calculous disease was considered the primary diagnosis in the remaining cases (Melicow).

The accepted treatment of papillary tumors of the renal pelvis is complete nephro-ureterectomy. In 1934 Kimball and Ferris were able to assemble 74 instances in which a papillary tumor involved the renal pelvis and ureter or bladder. In 33 per cent of the patients growths were present in the ureter and/or bladder as well as in the renal pelvis at the time of the initial examination. In the remaining patients new growths developed in the ureter and/or bladder after treatment of the original growth, usually by nephrectomy or by nephrectomy with incomplete ureterectomy. Of the recurrences in 50 patients, 24 (48 per cent) were at the ureteral orifice, 18 (36 per cent) at the ureteral orifice and bladder, 7 (14 per cent) in the bladder, and only 1 (2 per cent) in the ureter alone. The time before recurrence varied from one month to six years, but in 33 of the 50 cases it occurred within six months to three years. In the 74 cases, the original tumor was malignant in 38 and benign in 36 instances. In those with an originally malignant tumor the recurrences were usually malignant, and in those with originally benign tumors, the recurrences were usually benign. The high incidence of initial ureteral and vesical involvement, the high incidence of ureteral recurrence, and the occasional recurrence of an initially benign lesion as a malignant one clearly indicate the need for complete nephro-ureterectomy (including the intramural portion of the ureter) in the treatment of neoplasms of the papillary group.

TUMORS OF THE EPITHELIUM OF THE RENAL PELVIS

Neoplasms of the renal pelvis constitute between 5 and 10 per cent of all renal tumors and may be classified as:

A. Benign tumors
  (1) Papilloma
B. Malignant tumors
  (1) Papillary transitional cell, epidermoid, or squamous carcinoma
  (2) Nonpapillary transitional cell, epidermoid, or squamous carcinoma
  (3) Mucous adenocarcinoma

Ragins and Rolnick found the incidence of renal pelvis neoplasms among 122 nephrectomies for tumor to be 10.7 per cent. Kutzmann found a 6.2 per cent incidence of renal pelvis growths in an analysis of 3,499 renal neoplasms. Thomas and Regnier state that lesions of the renal pelvis constitute 5 to 7 per cent of all renal neoplasms. Priestley found 62 epitheliomas of the renal pelvis in 642 renal tumors, an incidence of 9.6 per cent.

The relative incidence of the various types of growths of the renal pelvis as approximated from a review of several authorities (Hunt; Melicow; Cahill; McDonald and Priestley; Kutzmann) is as follows:

		Per Cent
A. Benign Tumors	(1) Papilloma	30
B. Malignant Tumors	(1) Papillary Carcinoma (transitional cell, epidermoid or squamous carcinoma)	45
	(2) Nonpapillary Carcinoma	25
	(a) Transitional cell or epidermoid 10 per cent	
	(b) Squamous 15 per cent	
	(3) Mucous Adenocarcinoma—3 cases reported	

For all types of renal pelvis neoplasms the maximal age incidence is in the sixth decade with the great majority of cases occurring within the age range of 40 to 70 years. The sex incidence for these growths is predominantly male with a ratio of between 2:1 and 3:1, excepting the nonpapillary squamous carcinomas for which the sex incidence is approximately equal (Davidson).

The papillary lesions are usually transitional cell neoplasms similar to those occurring in the bladder and can be graded in a manner similar to bladder tumors. Although the etiology, as for other renal growths, is unknown occasional instances of papillary renal pelvis tumors have been reported among workers in the aniline dye industry (Macalpine), presumably caused by exposure to beta-naphthylamine. Squamous metaplasia occasionally occurs as a feature of papillary renal pelvis carcinoma, which accounts for the appearance of the designation "papillary squamous carcinoma" in the classification of renal pelvis neoplasms. The occurrence of such metaplasia is, however, commonly restricted to one or more localized areas in the tumor and, as far as can be determined, has no influence on the clinical behavior and prognosis of these lesions.

Both the nonpapillary carcinoma (especially the squamous variety) and the mucous adenocarcinoma are commonly associated with infection and frequently with calculus formation. For this reason the role of chronic irritation in their

ful review of the literature, they divided these tumors into four types: mixed tumors, carcinomas, sarcomas, and undifferentiated tumors. They support the concepts of Busse and Muus in postulating the origin of these tumors from the renal blastema and in deriving the various types of tissue encountered by a process of metaplasia.

(1) Mixed Tumors: The mixed tumors contain both epithelial and connective tissue elements typified by the so-called Wilms tumor. Varying degrees of differentiation are seen owing to the unlimited development potency of the embryonal cells. Occasionally areas of clear cell carcinoma are found. The authors add 4 such cases to the 97 similar mixed tumors found in the literature. The ages ranged from 16 to 80 years, with the greatest incidence during the sixth decade and the majority of patients falling between the ages of 40 and 70. There was a slight predominance of males. Eighty-four per cent of the patients had a palpable mass, 72 per cent complained of pain on the affected side, and 53 per cent had some degree of hematuria. Only 14 of the 64 patients in whom data were adequate, presented the complete triad of mass, pain, and hematuria. The average duration of symptoms was two years and seven months but excluding 5 cases with prolonged symptoms, the average was 12.5 months. Thirty of 45 patients known to be dead, died within about one year of nephrectomy. Metastases occurred most frequently in the regional lymph nodes, lungs, and liver, but also in bone, peritoneum, heart, contralateral kidney, thyroid, and brain. No correlation was found between survival and either the size or histology of the tumor, and there was no apparent advantage of transperitoneal over lumbar nephrectomy.

(2) Carcinoma: Culp and Hartman feel that many of the alleged renal sarcomas reported in the literature are in reality embryonal carcinomas and regard these tumors as potentially or actually mixed cell tumors in which the epithelial elements have outstripped other tissue elements. The authors found 18 such cases in the literature and added 3. Most of the patients with this type of tumor died following nephrectomy. No significant differences in clinical behavior could be found between this small group and the mixed cell tumors.

(3) Sarcoma: Culp and Hartman point out that the renal tubules normally develop from mesoblastic tissue, and that undifferentiated portions of epithelial tumors can therefore logically be expected to resemble the original mesoblast. They include the true sarcomas of adult kidney as one form of mesoblastic nephroma. Analysis of the reported cases indicates no significant clinical differences between these and the mixed cell tumors.

(4) Undifferentiated Growths: Although most of the highly malignant cortical neoplasms composed of primitive cells can be identified either as undifferentiated carcinomas or undifferentiated sarcomas, the occasional growth which defies such definition is relegated to this group (Culp and Hartman).

Embryonal Tumors of Children. Embryoma, mixed tumor, Wilms's tumor, and nephroblastoma are synonymous designations for neoplasms of this group. In the experience of Memorial Hospital, these growths are second in frequency in children only to neoplasms of the eye. Blacklock examined 100 consecutive malignant tumors in children and found that nephroblastoma was the second most common, constituting 21 per cent of the total. In spite of these data, how-

McDonald and Priestley in 1944 reviewed 75 cases of tumors of the renal pelvis. Among 27 patients with papillary growths without infiltration there was a 52 per cent five year survival; * among 25 patients with papillary lesions with infiltration, a 16.7 per cent five year survival; and among 23 patients with nonpapillary lesions, a 7.1 per cent five year survival.† Hydronephrosis was noted in 53 or 70.7 per cent of the cases. The incidence of ureteral and vesical involvement was, respectively, 41 per cent and 44 per cent for the noninfiltrating papillary tumors and 24 per cent and 20 per cent for the papillary infiltrating growths. Only the upper end of the ureter was ever involved by the flat infiltrating neoplasms (McDonald and Priestley).

Priestley found the survival * rate for the entire group of tumors of the renal pelvis to be 44.7 per cent at three years, 35 per cent at five years, and 10.5 per cent at 10 years. Of the factors influencing prognosis, the grade of the tumor is of obvious importance. In a series of 75 cases, the five year survival was 63.2 per cent for grade I and II lesions and 13.2 per cent for grade III and IV lesions (McDonald and Priestley). Of 34 patients without venous or lymphatic involvement, 16 (47.1 per cent) survived five years †, whereas of 23 patients with venous or lymphatic involvement only 1 (4.3 per cent) lived five years. As anticipated, the incidence of infiltration and of venous and lymphatic invasion increased with the grade of the tumor.

Squamous cell carcinoma of the renal pelvis is a flat infiltrating growth with an insidious onset and a fatal course. In 1942 Davidson could find no five year cures reported in the literature. The preoperative diagnosis is rarely, if ever, made. Kutzmann in 1938 reviewed the literature and found a total of 81 cases of squamous carcinoma of the renal pelvis, 11.9 per cent of which had an associated leukoplakia of the renal pevis. This tumor is almost always associated with infection and/or stone. Pain, frequently due to infiltration of the renal hilus and adjacent structures, is the most common symptom, occurring in approximately 60 per cent of cases. Hematuria, weight loss, and the presence of a mass are each noted in about half of the cases. Pyelography usually leads to the diagnosis of the associated condition, e.g., nonfunctioning kidney, calculous disease, hydronephrosis, and, more rarely, tumor, The treatment is nephrectomy, but because these tumors have usually infiltrated directly through the pelvis into the surrounding tissues, incomplete removal with subsequent rapid recurrence is the rule. The majority of patients die within a year of operation. Distant metastasis may occur but local recurrence is usually the most striking feature.

Embryonal Tumors

Embryoma of the kidney constitutes one of the most common forms of cancer in childhood. In adults, however, these tumors are quite rare.

Embryonal Tumors of Adults. In 1947 Esersky, Saffer, Panoff, and Jacobi assembled 56 cases of Wilms' tumor in adults. Culp and Hartman suggest the term mesoblastic nephroma for these tumors of embryonal origin. In their care-

* The survival rates are calculated from the number of traced patients who submitted to nephro-ureterectomy (or nephrectomy).

† The survival rates are calculated for the number of traced patients who submitted to nephro-ureterectomy (or nephrectomy) and who were not postoperative deaths.

Because children in this age group are usually unable to report early signs and symptoms, the diagnosis is not usually made until one of the parents incidentally palpates the neoplasm. There may be a history of low grade fever, ill defined abdominal pain, irritability, nausea, vomiting, or weight loss. The presenting symptom is a mass in 70 per cent, pain in about 20 per cent, and hematuria in about 10 per cent of the cases. On examination a large smooth mass is almost invariably felt in the flank. This is rubbery and nontender and may be fixed. Apparent fixation is no contraindication to attempting nephrectomy since it may result merely from the enormous size of the tumor. In the majority of cases diagnosis will be suspected from the history and examination. Intravenous pyelography will usually establish the diagnosis with reasonable clinical certainty and demonstrate the status of the other kidney, but retrograde pyelography may be necessary in rare instances. The pyelogram is apt to show distortion and displacement. Such displacement may be forward or backward, upward or downward, medially, but seldom laterally (Gross and Neuhauser). Function of the affected kidney may be impaired to some extent but is usually present.

The treatment of Wilms's tumors of the kidney has passed through various phases and no attempt will be made to review the history of the different therapeutic methods. At the present time the majority of clinicians feel that a combination of nephrectomy with roentgen therapy offers the greatest prospect of benefit. Opinion differs, however, as to when this roentgen therapy should be administered. The use of preoperative roentgen therapy has gradually lost its popularity. The fact that a positive pathologic diagnosis is usually not available preoperatively and the delay in operation necessitated by preoperative irradiation are the chief arguments against its use. Irradiation usually cause a reduction in the size of the tumor and may thus reduce handling and the danger of rupture, and facilitate surgical removal. However, immediate nephrectomy is finding increasing favor as the method of management. Postoperative roentgen therapy is given by most clinicians and there is increasing evidence that such therapy is beneficial. The clinical effectiveness of postoperative irradiation is evidenced by two observations:

(1) The established curative effects of irradiation on regional extensions and even on pulmonary metastases in rare instances. Nesbit and Adams report 2 cases in which regional retroperitoneal infiltrations were left behind during nephrectomy for Wilms's tumor; both cases were successfully treated by postoperative irradiation. In a third case the patient had a Wilms's tumor by biopsy and questionable roentgenologic evidence of right pulmonary metastases; both the primary tumor and the apparent metastases were treated by irradiation only with apparent cure 10 years later. Kerr and Silver each report an instance of apparently successful radiation control of pulmonary metastases which developed following nephrectomy for Wilms's tumor. Gross and Neuhauser cite "several children treated by nephrectomy, but in whom extensions of neoplasm were known to be left around the aorta or vena cava" who obtained long term survivals, presumably because of postoperative irradiation. Gross and Neuhauser advise extensive irradiation for those patients who are treated by nephrectomy, but who have evidence of local extension or local metastasis in the abdomen at the time of operation or subsequent thereto, without evidence of metastasis outside the

ever, Wilms's tumor cannot be considered common either among children as a whole or among all renal neoplasms. In Priestley's large series embryomas constituted 37 (5.8 per cent) of 642 cases and in Melicow's series 9 (4.5 per cent) of 199 cases of renal neoplasm. The sex incidence of these growths is equal. Although cases have been reported in the fetus, the average age of patients with Wilms's tumors is two to three years. According to Cahill more than 80 per cent of the reported cases have occurred before the seventh year. Maslow has reported 3 cases of proved Wilms's tumor and a possible fourth case occurring in the same family, all in children ranging in age from 13 months to four years. Wilms's tumors are usually unilateral and the high incidence of apparent bilaterality reported by Wilms (7.2 per cent) and by Kretschmer and Hibbs (12 per cent) is probably attributable to the tendency to metastatic involvement of the contralateral organ.

The pathogenesis of Wilms's tumors has been a subject of widespread interest and discussion. The concepts of embryogenesis most commonly accepted at the present time are attributable to Busse and Muus who postulated the origin of these neoplasms from a segregated portion of the renal blastema which failed to develop normally during fetal life but which retained its full mesenchymal multipotency, not only to develop primitive tubules and glomeruli, but also to exhibit metaplastic tendencies in the formation of smooth and skeletal muscle and cartilage. Masson has found sympathetic nerve elements in these tumors and suggests that the growths may develop from a rest that separates at an earlier embryologic period than that of the metanephrogenic mass or even the primitive undifferentiated mesoderm. He describes a "neuroepithelium" from which neuro-ectodermic elements and nephrogenic mesenchyme develop and attributes the mixed tumor of the kidney to misplaced neuro-epithelial elements.

In spite of the fact that these neoplasms are undoubtedly congenital, Farber in 3,000 necropsies on children found no Wilms's tumors, and Wells, in an equal series on premature fetuses and stillborns, found none. These tumors may grow to enormous size, sometimes occupying the greater portion of the abdomen. In spite of their huge size, they tend to remain within the renal capsule, which prevents their spread to adjacent viscera. Although the kidney may be stretched like a shell over the surface of the tumor, there is usually a fairly sharp line of demarcation between the renal parenchyma and the tumor. Cystic degeneration and hemorrhage are common. The growths are usually smooth but may be slightly lobulated. Microscopically a tremendous degree of variation is possible. Typically the tumor contains primitive epithelial elements, suggesting abortive efforts at the formation of tubules and glomeruli, embedded in a sarcomatous stroma. The degree of differentiation of epithelial elements may vary widely. Smooth and striated muscle, fat, and cartilage are not uncommon. Large and thin-walled vessels are a conspicuous microscopic feature and help to account for the frequency of blood-borne metastases. McCurdy, in a review of 27 mixed tumors of childhood, found primitive glomeruli in 56 per cent, striated muscle in 37 per cent, and smooth muscle in 64 per cent of the cases. It has been suggested that the occasional round cell sarcoma occurring in children may result from the inability of the nephrogenic blastema to differentiate into tubules and glomeruli in the absence of collecting tubules (Seevers).

of copper, with a target skin distance of 50 cm. and HVL equal to 1.05 mm. copper.

Gahagan and Yearwood could find no reported death from Wilms's tumor after survival for five years, but cite Abbe as reporting a patient who lived four years and nine months and subsequently died of metastases. The great majority of patients with Wilms's tumor who are not successfully treated die within two years of the time of diagnosis and most such patients do not survive a year.

In 1951 Rusche assembled 72 five year survivals following treatment for embryoma, including 5 personal cases. Of these 72 cases, 31 had been treated by nephrectomy alone, 9 by preoperative irradiation and nephrectomy, 12 by nephrectomy and postoperative irradiation, 9 by preoperative irradiation, nephrectomy, and postoperative irradiation, and 11 by irradiation alone. Not all of the patients receiving roentgen therapy only had proof of Wilms's tumor by biopsy and accordingly, there is some question regarding the validity of that group.

It is impossible to estimate the prognosis from the pathologic features of the tumor itself. The metastasis may look entirely different from the primary tumor and it is the most anaplastic element which is likely to metastasize first and most abundantly (Allen). Differences in the pathologic make-up of the tumor explain differences in radioresponsiveness both of the primary tumor and of its metastases. No definite relationship between the size of the tumor and the prognosis has been observed. The most striking factor in prognosis seems to be the age of the patient at the time the disease is treated. Children less than one year of age have a much better prognosis than children older than one year, presumably because the tumor has been present for a longer time in the latter group. Ladd and White found that all patients who had renal vein invasion or gross hematuria died. Wilms's tumors invade the blood stream and lymphatics early and those patients who are not cured generally succumb rapidly to the effects of pulmonary metastases or massive intra-abdominal recurrence. Bone metastases occur rarely.

The association of hypertension with Wilms' tumor has been noted but the meager clinical data do not permit final evaluation of the significance of the observations. Daniel noted elevation of the blood pressure in 14 of 18 cases and found no relation between the pathologic features of the neoplasm and the occurrence of hypertension. Three patients had marked reductions in blood pressure within three weeks after roentgen therapy to the growth. One patient whose hypertension failed to improve on roentgen therapy also failed to have a fall in blood pressure after nephrectomy. One patient with extreme hypertension which was reduced by roentgen therapy had a return of hypertension when the lesion recurred following nephrectomy. Daniel considers renal ischemia due to pressure of the growth as the most likely cause of the hypertension. Only patients living as long as 12 months without evidence of local recurrence or metastasis had normal blood pressures when first seen, suggesting that hypertension associated with embryoma may be indicative of tumor growth in the region of the great vessels (Daniel).

Bradley and Pincoffs reported the concurrence of arterial hypertension in 5 consecutive cases of Wilms's tumor and concluded that the neoplasm was in some way responsible for the hypertension. In 2 cases removal of the growth resulted in

abdomen. They believe roentgen therapy is hardly worth giving in the patients with widespread pulmonary metastases, but that limited pulmonary metastases should probably be treated intensively as long as there is no evidence of further dissemination of the disease.

(2) The superior survival rates in patients who have received postoperative irradiation when contrasted with a comparable group who have not been irradiated. This is best indicated in the survival rates cited by Gross and Neuhauser (Table II) wherein the difference in survival rates between groups II and III is attributed primarily to the use of postoperative irradiation in the latter group.

TABLE II

STATISTICS FROM BOSTON CHILDREN'S HOSPITAL SERIES OF MIXED TUMORS OF THE KIDNEY*

Probable Cures

Period of Study	Pts. below 12 mos. of age	Pts. above 12 mos. of age	All pts. of all ages
GROUP I			
1914-1930 Inclusive	7 cases	20 cases	27 cases
	3 cures	1 cure	4 cures
	42.8 per cent	5 per cent	14.9 per cent
GROUP II			
1931-1939 Inclusive	7 cases	24 cases	31 cases
	5 cures	5 cures	10 cures
	74.1 per cent	20.8 per cent	32.2 per cent
GROUP III			
1940-1947 Inclusive	5 cases	33 cases	38 cases
	4 cures	14 cures	18 cures
	80 per cent	42.4 per cent	47.3 per cent

* From Gross, R. E. and Neuhauser, E. B. D.: *Pediatrics*, 6.843, 1950.

Most clinicians now agree on the necessity for prompt nephrectomy in the treatment of Wilms's tumors. Ladd and White and subsequently Gross and Neuhauser have indicated a preference for transperitoneal nephrectomy which permits early ligation of the renal pedicle with minimal handling of the tumor. In addition, these authors recommend that the same surgeon or the same small group of surgeons perform these operations.

In the first group of cases (Table II) the patients were operated on by a number of different surgeons and the operative mortality alone was 23 per cent. In the second group of patients there were no deaths after 1932 owing to improvements in preoperative and postoperative care and in surgical technic, and the universal use of the transperitoneal approach for the removal of the larger tumors. In the third group of patients there were no deaths. The third group differs from the second group primarily in the fact that postoperative irradiation was given in all but 2 cases, and the rise in the cure rate is attributed largely to its use. Roentgen therapy is begun immediately after completion of the operation and before the patient recovers from the anesthesia. Treatment is given in daily doses of 200 r, using anterior, lateral, and posterior portals over the tumor bed in sequence for a total of 4000 to 5000 r (measured in air), and employing a 200 KV machine with filters of 1 mm. of aluminum and 0.5 mm.

of copper, with a target skin distance of 50 cm. and HVL equal to 1.05 mm. copper.

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a fall in blood pressure which returned to hypertensive levels with recurrence of the tumor. These writers were unable to find a pressor substance in the neoplasms, but felt that the tumor tissue, through as yet unknown mechanisms, produced an elevation in arterial pressure.

SECONDARY TUMORS OF THE KIDNEY

Secondary tumors of the kidney can be divided into two groups:

(A) *Those involving the Kidney by Direct Extension*

(1) By extension from a retroperitoneal node metastasis from a primary tumor elsewhere: Carcinoma of the testis with retroperitoneal node involvement and secondary renal invasion is an illustration of this. Another illustration is furnished by retroperitoneal node enlargement with renal invasion secondary to Hodgkin's disease.

(2) By extension from a retroperitoneal viscus: Carcinoma of the adrenal, particularly neuroblastoma, with renal invasion is well known in children. These growths may be difficult or impossible to differentiate clinically from a primary Wilms' tumor. Neuroblastoma is more likely to displace the kidney laterally than is a Wilms tumor and frequently metastasizes to the bones, lymph nodes, and lungs. Approximately 60 per cent of these tumors arise in the adrenal medulla or neighboring ganglia in close proximity to the kidney. The tendency of neuroblastomas to exhibit calcification is a differential feature.

(3) By extension from an intraperitoneal viscus: Extension from carcinoma of the colon only rarely involves the kidney directly although ureteral obstruction and invasion by an adjacent carcinoma of the colon is well known.

(4) By extension from a pararenal tumor: This subject will be discussed in another section.

(B) *Involving the Kidney by Metastasis*

(1) Lymphomas: The tumors which most commonly metastasize to the kidney are undoubtedly the lymphomas. According to Ewing, the kidney is a favorite site for metastases from lymphosarcoma. Kirshbaum and Preuss in a review of 123 cases of fatal leukemia found definite leukemic infiltration of the kidney, both nodular and diffuse, in 63 per cent of the patients. There was no recognizable preference of any type of leukemia for any special organ or organ system, but the kidney was most frequently involved in all forms. Myeloid or lymphoid cells were found in the glomerular tufts or in the interstitial tissues. Barney reported renal involvement in 18 of 23 cases of lymphoblastoma of the urinary tract coming to autopsy. Baldridge and Awe found microscopic evidence of renal invasion in 27 of 39 cases with lymphoma of various types, but the highest incidence of renal involvement occurred in the lymphocytic type of leukemia in which 17 of 17 cases showed renal involvement. Gowdey and Neuhauser point out that diffuse leukemic infiltration may cause marked renal enlargement with elongation of the pelvis, infundibuli, and calyces. However, diodrast clearance is well preserved and there is no evidence of multiple, rounded, pressure defects. They point out that irradiation might logically be expected to improve this picture.

Although lymphoblastomatous involvement of the urinary tract is common at

autopsy, clinical manifestations are infrequent, and, owing to the rarity of clinical symptoms, the urologist is rarely called to see these patients (Watson, Sauer, and Sadugor). Occasionally a case of lymphoma presents with urinary tract symptoms and may present diagnostic problems. Many cases have had ill advised surgical procedures because of inability to make a correct preoperative diagnosis. In a review of 1,073 cases of lymphoblastoma, these authors found 456 cases of lymphosarcoma, 234 cases of leukemia, and 383 cases of Hodgkin's disease. In 80 patients or 7.5 per cent of the cases there was clinical evidence of urinary tract involvement; 32 or 13.6 per cent of 234 leukemia patients; 43 or 9.5 per cent of 456 lymphosarcoma patients and 5 or 1.3 per cent of 383 patients with Hodgkin's disease. In 143 autopsied cases of lymphoma 62 or 43.3 per cent had urologic involvement: 27 or 58.6 per cent of 46 leukemias; 32 or 61.9 per cent of 52 lymphosarcomas; and 3 or 6.6 per cent of 45 cases of Hodgkin's disease. The clinical and laboratory findings of urinary tract involvement are often absent even in advanced cases. Of the 80 patients with advanced disease and urinary tract involvement, 57 or 71.3 per cent had no urinary symptoms. In the remaining 23 patients hematuria occurred in 6, uremia in 3, and renal pain in 2. Of 80 patients 66, or 82.5 per cent, had renal involvement, including 34 of 43 patients with lymphosarcoma, 30 of 32 patients with leukemia, and 2 of 5 patients with Hodgkin's disease. With regard to renal involvement it was noted that (a) renal displacement by retroperitoneal nodes or by splenic or hepatic enlargement was common; (b) retroperitoneal nodes invading the kidney were uncommon but frequently such node involvement surrounded the kidney; (c) multiple nodules in the kidney were the most common form of renal involvement and occasionally caused gross hematuria or uremia; (d) microscopically the nature of the parenchymal involvement was apt to vary from a diffuse type to a perivascular or a periglomerular type of infiltration.

(2) Carcinomas: A total of 1,481 cases of carcinoma metastatic to the kidney has been reported (Pine). Among 407 cases of cancer Pine found 19 instances of metastasis to the kidney. The tumors were cortical and not extensive enough to produce any defect in the pelvis or caliceal system. The lesions varied in diameter from 2.5 to 9 mm. The incidence of metastasis to the kidney is highest with primary carcinoma of the kidney, with carcinomas of the lung, breast, esophagus, sigmoid, and pancreas following in that order.

(3) Sarcomas: Occasional instances of clinical involvement of the kidney by metastases from osteogenic sarcoma have been reported (Marshall and Drake). Metastases to the kidney from melanoma are sometimes found in the advanced stages of the disease.

(4) Endometriosis: Marshall in 1943 reported a large growth of the kidney in a 46 year old woman who complained of pain and swelling of the flank and who on roentgen examination showed a definite deformity on the pyelogram suggestive of renal tumor. Pathologic examination of the removed kidney revealed tissues which were distinctly endometrial in appearance. A similar lesion has recently been reported by Maslow and Learner in a 29 year old woman who had noncyclic hematuria. The origins of such tumors are naturally speculative, and their inclusion in the group of tumors metastatic to the kidney is based on present concepts of the pathogenesis of endometriosis.

PARARENAL TUMORS

The term "pararenal" should be employed to designate structures outside the confines of Gerota's fascia but adjacent to the kidney, and obviously includes a great variety of tumors arising from the tissues of the retroperitoneum, both benign and malignant. More specifically it includes those tumors of teratoid nature, namely the teratomas and dermoid cysts, which involve the kidney primarily by contiguity. Baker and Ragins in 1950 found 15 instances of pararenal teratoma in the literature and included both teratomas and dermoids in their review.

In the 9 patients included in Valentine's review of dermoids of the kidney, the ages ranged from 11 to 58 years. Five were in females, 2 were in males, and in the remaining cases the sex was not stated. Five of the tumors contained hair while the appended descriptions on the other 4 cases leave some doubt of their dermoid nature. In 6 patients a palpable tumor was present and in one there was hematuria. Campbell, in a review of 4 cases of pararenal teratoma, suggested that roentgen studies might occasionally show bone within these lesions, thus giving a clue to the diagnosis. The tumors are usually benign but may occasionally undergo malignant change. Anlyan and Harper recently reported the successful removal of a retroperitoneal teratoma from a five month old girl in whom the presenting symptom was an abdominal mass.

TUMORS OF "REST" ORIGIN

Adrenal Rest Tumors: Allen reports a 1 per cent incidence of adrenal rests beneath the renal capsule near the upper pole in routine autopsy material. The bulk of evidence indicates that renal adenocarcinomas have no connection with adrenal rests, and that the true hypernephroma occurs but rarely. Riopelle has recently discussed the subject of hypernephroma and concludes that it is a distinct entity rather than a mere histologic variant. He considers it to be the result of neoplastic development of a renal fibromyolipoma containing epithelial inclusions.

Chondral and Osseous Rests: Chondral and osseous rests occasionally occur within the renal parenchyma, particularly in the medulla (Allen). The bone is probably metaplastic but the islands of cartilage usually represent true rests. There is no evidence to suggest that such rests ever give rise to neoplasms.

On the clinical level, hope of improving the present picture of prognosis in renal tumors rests with two possibilities: (1) earlier diagnosis; (2) more effective treatment.

DIAGNOSIS

It has been repeatedly stated that the first requisite for the diagnosis of any condition is an awareness of the possibility of its occurrence. Renal tumors constitute no exception, and indeed the range of bizarre clinical manifestations in which a renal neoplasm may cloak itself is unsurpassed by any other neoplasm, further emphasizing the need for awareness. The physician must next have a reasonably complete knowledge of the weapons in his diagnostic armamentarium,

not only with respect to their virtues but also with regard to their limitations. Here it becomes evident that our methods of diagnosis are still extremely crude and that truly early renal tumors are rarely discovered and then usually through chance rather than intent. Nevertheless, until more refined technics of diagnosis become available it is important to take full advantage of the present tools.

Complete and Detailed History

The clinical manifestations of renal tumors have already been reviewed. The absence of the classical or typical symptoms does not rule out the possibility of a renal neoplasm.

Careful Physical Examination

The usual physical signs of renal growths have been previously discussed. Their absence does not exclude the possibility of such a lesion.

Urinalysis

In Rolnick's series 25 per cent of patients with renal tumors had a normal urinalysis. Hematuria should be a signal for immediate cystoscopy—a perhaps never to be repeated opportunity to observe directly the source of the bleeding.

Papanicolaou Smear of the Urinary Sediment

Stained smears of the urinary sediment examined by a qualified cytologist have proved to be a useful adjunct in the diagnosis of renal neoplasms. The method is useful in the differential diagnosis of filling defects in the renal pelvis, and for investigation of calculous disease and pyelonephritis in which concomitant carcinoma of the renal pelvis is suspected. For other types of renal growths, especially the renal adenocarcinomas, Wilms tumors, and benign papillomas of the renal pelvis, its diagnostic value has been quite limited. Foot and Papanicolaou have reported a patient in whom nephrectomy was performed on the basis of hematuria and repeatedly positive cytologic studies from a kidney which was pyelographically normal. Although no gross lesion was detectable in the removed kidney, multiple sections revealed carcinoma in situ apparently arising from multiple foci in the collecting tubules, calyces, and pyramids. Bunge and Kraushaar report a 48 year old man who had a left nephrectomy on the basis of abnormal urinary cytology and microscopic hematuria, and who was found to have a small renal adenocarcinoma. These same authors report 2 cases in which the removed kidneys were normal despite the report of abnormal cytology.

Bothe, Dalton, and Zillessen found the number of mitochondria and amount and pattern of Golgi material to be similar in the cells of renal adenocarcinoma and uninvolved parenchyma, but the mitochondria in nonlipoid-containing cells of clear cell carcinoma were greater in number and smaller in size than the mitochondria of the uninvolved parenchymal cells. The Golgi material was greatly increased in amount in such cells over that seen in normal parenchymal cells. Such studies may broaden the value of the cytologic study in the diagnosis of renal neoplasms. At present the Papanicolaou technic constitutes an occasionally useful supplement to other methods of diagnosis.

Radiography

Radiography still provides the best methods for the clinical diagnosis of renal tumors. On the plain film one looks for deformity of the renal outline, enlargement of the renal outline, displacement of the kidney, and abnormal calcification. On the intravenous and retrograde pyelograms one looks for deformity of the calyces or pelvis, which may take the form of compression, dilatation, elongation, displacement, or partial or complete obliteration. The spider-like pyelographic deformity usually described as typical of renal neoplasm is often absent. A high index of suspicion will do much toward the earlier diagnosis of renal neoplasms which have produced only minor deformity in the renal outline or pyelogram. Occasionally intravenous pyelography will give all the information that is necessary. Usually, however, retrograde films with lateral and oblique views of the suspicious kidney will permit a more definitive diagnosis.

The differential diagnosis between renal cyst and tumor cannot be made with certainty by radiographic means. Lindblom has suggested needle injection of diodrast directly into the renal mass in order to distinguish between cyst and tumor. Aspiration of the cyst contents or aspiration biopsy of the tumor has also been suggested as a means of differentiation.

Vesey, Dotter, and Steinberg have described a technic of nephrography involving the rapid intravenous injection of approximately 50 cc. of contrast medium intravenously within two seconds and roentgenographic exposure of the abdomen 16 to 22 seconds later. This resulted in excellent demonstration of the renal shadows in 18 of 25 cases. The authors point out that nephrography might prove to be of value in the differential diagnosis of renal cyst and carcinoma since renal cysts generally produce areas of radiolucency in the renal shadow whereas pooling of contrast medium in carcinomatous lesions has been described. Rapid serial roentgenography is suggested as a means of increasing the value of nephrography in the study of renal lesions. Nephrography may also prove of value where intravenous and retrograde pyelograms are inadequate. Weens and Florence devised a technic of nephrography employing an obstructing ureteral catheter in association with intravenous pyelography.

Abdominal aortography, described by dos Santos, Lamas, and Pereira and by Nelson, obtains increased renal opacity by direct translumbar injection of radiopaque medium into the abdominal aorta above the level of the renal arteries. Nelson was able to demonstrate bilateral renal neoplasms when both intravenous and retrograde pyelography had failed. The method has been used by Wagner to delineate the arterial supply of a large renal tumor. It requires the use of general anesthesia and has in one case been followed by death due to superior mesenteric artery thrombosis (Vesey, Dotter, and Steinberg). A technic of retrograde catheterization of the aorta to the desired level through the lateral circumflex branch of the profunda femoris has been employed for aortography and renal arteriography by Goodwin, Scardino, and Scott. Perirenal air insufflation and laminography are occasionally used to obtain better definition of the renal and adrenal shadows. Leadbetter has recently described an instrument for the visualization of the renal pelvis at operation.

TREATMENT

On June 4, 1861, Erastus B. Wolcott, a Midwestern surgeon, performed the first successful nephrectomy which, incidentally, was for a renal cancer (Gilbert). The patient was a 58 year-old man who had been in poor health for the previous six years, was anemic, and had a large mass filling the right upper quadrant of the abdomen. The mass was thought to be a cystic tumor of the liver. Under chloroform anesthesia an oblique incision was made over the mass, the peritoneum was retracted, and a 2½ pound renal tumor removed. The patient lived 15 days after the operation and seemingly died from exhaustion.

Since Wolcott's initial effort improvements in preoperative and postoperative care, in methods of anesthesia, and in operative technic have combined to produce a progressive drop in the operative mortality of nephrectomy to approximately 1 per cent.

Although there are no data on the survival of patients with untreated renal cancer, there is abundant clinical evidence to suggest that spontaneous cures are extremely rare, if they occur at all, and that the disease runs a generally progressive and fatal course in untreated, as well as in most treated patients. Welch and Nathanson recorded survival data on 45 patients with treated renal cancers. As calculated from the date of clinical onset, 25 per cent of the cases were dead in 10 months, 50 per cent in 22 months, 75 per cent in 37 months, and 86.5 per cent in five years. The successful treatment of renal cancer depends on the complete surgical eradication of the primary neoplasm before distant metastasis or inoperable local extension has occurred. Exceptions to this generalization could be the few Wilms tumors which seem to have been successfully treated by irradiation alone, or by a combination of surgery and irradiation. Although the present five year survival rates for the different forms of renal cancer following nephrectomy indicate that definite progress has been made, much yet remains to be accomplished. For those patients who have distant metastases or inoperable local extensions at the time of diagnosis, present therapeutic methods offer little prospect of cure.

For patients whose renal cancers are still regional or local at the time of diagnosis, nephrectomy has proved to be a usually safe and occasionally effective method of treatment. Whatever prospects there may be of improving the survival rates in patients so treated, may logically be expected to depend on improvements in operative technic and, for Wilms's tumors, radiation technics.

It is well established that the successful treatment of any cancer depends on a detailed understanding of the life history and mode of spread of the particular neoplasm, and, as a corollary, a knowledge of the causes of treatment failure. This is perhaps best illustrated in carcinoma of the breast where a knowledge of the methods of spread of breast cancer and recognition of the limitations of simple mastectomy have permitted a reasonable salvage of patients with axillary metastases by the use of a carefully planned operative procedure, which removes not only the primary tumor, but also its principal areas of lymphatic drainage.

CONDITIONS AFFECTING PROGNOSIS

For renal cancers there are three important local features which might be expected to influence the end results following nephrectomy:

The Tendency Toward Direct Perirenal Extension. Renal Adenocarcinoma: The tendency for perirenal extension is particularly marked in the larger renal adenocarcinomas. Snelling found perirenal infiltration in 7 (25 per cent) of 28 patients subjected to nephrectomy for renal adenocarcinoma in whom detailed pathologic data were available. Although an undetermined number of local recurrences must be attributed to tumor remaining in the renal vein or inferior vena cava, or to residual disease in the regional lymph nodes, some undoubtedly result from incompletely removed perirenal extensions. How often such recurrences, either directly or indirectly (*i.e.*, by metastasis originating in the local recurrence), are responsible for the fatal outcome cannot be estimated from available data. Although the presence of perirenal extension is generally agreed to be associated with a poor prognosis (Priestley; Fetter) it cannot be inferred that such extension is *per se* the cause of the poor prognosis.

Hovenanian has described the occurrence of a metastatic focus of renal adenocarcinoma in the homolateral lower ureter and cites Macalpine as having had a similar case. The rarity of such occurrences, however, does not justify the addition of ureterectomy to the present surgical therapy for renal adenocarcinoma.

Epithelial Tumors of the Renal Pelvis: The tendency for direct perirenal extension is evident in nonpapillary epidermoid carcinoma of the renal pelvis, especially squamous carcinoma, and is reflected in the almost inevitable, prompt, massive, local recurrence which follows nephrectomy for this neoplasm. Here again, the exact role of venous invasion and lymphatic extension in the development of such recurrence is speculative. In these patients death is frequently the result of the extensive local recurrence although metastases to the lungs, liver, and bones do occur. Although papillomas and papillary carcinomas of the renal pelvis show no such extreme tendency toward direct perirenal extension, local recurrences do occasionally take place, a development commonly attributed to the seeding of tumor cells in the wound at the time of nephrectomy (Macalpine).

Whether the new tumors which tend to develop in the ureter and/or bladder following simple nephrectomy for papillary tumors of the renal pelvis result from direct implantation of tumor cells on the epithelial lining of the urinary tract, from lymphatic emboli from the original lesion, or from multicentric foci of origin is still unsettled. The last concept seems most tenable. In any event the occurrence of such "recurrent" tumors can be most conveniently considered at this time as a form of "perirenal extension."

Flat infiltrating carcinomas of the renal pelvis, in spite of the high incidence of local recurrence, do not tend to recur in the ureter or bladder. The upper portion of the ureter may be involved by direct extension from the primary tumor, and recurrences may so infiltrate the retroperitoneal tissues as to encase the ureter in a solid mass of tumor, but there is no evidence to indicate that total ureterectomy should be made a part of the operative procedure for the treatment of this particular neoplasm. Priestley and McDonald found direct in-

volvement of the upper end of the ureter in 3 (13 per cent) of 23 patients with flat infiltrating lesions.

For papillary tumors of the renal pelvis the evidence clearly indicates the desirability of combining total ureterectomy, including the intramural portion of the ureter, with nephrectomy in the treatment of these neoplasms (Kimball and Ferris; Thomas and Regnier; McDonald and Priestley).

Embryonal Tumors: Although the Wilms' tumor is encapsulated for the greater part of its life history, rupture of the capsule and invasion of adjacent viscera occasionally occur. The abdominal mass which is the presenting symptom in the great majority of children with this neoplasm is frequently evident again before the child dies of the disease. Although there is no documentary evidence to indicate that treatment failures in children with these growths can be due solely to failure to remove perirenal extensions, the known occurrence of such extensions and of local recurrences suggests that such might occasionally be the case. The relative importance of perirenal extension, venous invasion, and lymph node involvement in the development of local recurrences cannot be estimated from presently available data.

The Tendency Toward Direct Venous Invasion. Renal Adenocarcinoma: Renal adenocarcinoma exhibits a marked tendency toward venous invasion. Beer reported evidence of tumor thrombus formation in 50 (38.5 per cent) of 130 cases of renal adenocarcinoma, in 8 of which the thrombus extended into the inferior vena cava. Bonnecarrere found invasion of the small intrarenal veins in 12 (37.5 per cent) of 32 cases and invasion of the main renal vein in 3 of 32 cases of epithelial kidney tumors.

In 28 carefully studied patients with renal adenocarcinoma treated by nephrectomy, the tumor was completely localized to the kidney in only 11, or 39.3 per cent. In the remaining 17 cases there was renal vein involvement (7 cases), regional node invasion (3 cases), or perirenal infiltration (7 cases) (Snelling). McDonald and Priestley found tumor thrombosis of a main renal vein in 275 (54 per cent) of 509 cases of renal adenocarcinoma and point out that the tumor thrombus becomes firmly attached to the intima of the vein as it grows, acquiring a blood supply from the wall of the vessel, and behaving as a sort of parasitic thrombus. This observation indicates the necessity for complete excision of the vein to a point beyond the site of attachment of the thrombus.

That tumor thrombosis of the renal vein is associated with the prognosis following nephrectomy for renal adenocarcinoma is indicated by the five year survival rate of 55.5 per cent for patients without tumor thrombosis and 29 per cent for patients with tumor thrombosis (McDonald and Priestley). The same authors found a higher incidence of tumor thrombosis in grade III and IV lesions than in grade I and II lesions, the incidence being 61.9 per cent and 49.8 per cent, respectively. It is evident that even low grade renal adenocarcinomas have a marked tendency to invade the veins, and that no matter what the grade of the tumor, venous invasion is associated with a lower survival rate. The incidence of tumor thrombosis of the renal vein increased slightly with the weight of the involved kidney (McDonald and Priestley).

Thus, venous invasion is a common finding in renal adenocarcinoma and its

presence is associated with a poor prognosis. However, it cannot be inferred from these facts that renal vein invasion is the cause of the poor prognosis. Renal vein thrombosis may be interpreted as merely one other manifestation of an insidious neoplasm which is well advanced locally and perhaps systemically at the time of the initial diagnosis. That the presence of massive tumor thrombosis increases the risk of tumor embolism seems probable, but that such embolism is synonymous with tumor metastasis can be summarily denied.

Although the necessity for early ligation of the renal vein has been stressed by virtually every living author on this subject, there is no conclusive evidence to indicate that survival rates are affected by this measure. The 38 per cent five year survival rates for renal adenocarcinoma reported by Priestley and by Foot, Humphreys, and Whitmore were obtained primarily by the use of the standard lumbar or posterolumbar incision in which some if not considerable manipulation of the kidney is necessary before the pedicle is finally secured. Although early ligation of the renal pedicle constitutes good surgical technic, it has not yet been shown to have improved the survival rates of patients with renal adenocarcinoma.

Epithelial Tumors of the Renal Pelvis: Among 75 cases of carcinoma of the renal pelvis (McDonald and Priestley), the renal vein or its tributaries was involved in 31 (41.3 per cent) cases, 21 of which had involvement of the main renal vein. Perineural lymphatic involvement was noted in 23 (30.7 per cent) cases, only 3 of which did not have simultaneous venous involvement. The renal artery was involved only once and that in a patient who also had renal vein and lymphatic involvement. That the presence of venous or lymphatic involvement is associated with a poor prognosis is indicated by the 47.1 per cent five year survival of 34 traced patients (who survived operation) without such involvement as contrasted with the 4.3 per cent five year survival of 23 traced patients (who survived operation) with such involvement. The incidence of venous or lymphatic invasion or both was highest in the nonpapillary lesions. The high local recurrence rate of nonpapillary infiltrating tumors may be a manifestation of local extension and/or lymphatic and venous invasion. The relative importance of these several factors cannot be evaluated from current data.

Embryonal Tumors: McDonald and Priestley report tumor thrombosis of the renal vein or involvement of the perineural lymphatics or both in 14 (45.2 per cent) of 31 cases of Wilms's tumor. Perineural lymphatics were involved in 2 cases, one of which also had tumor thrombosis in the renal vein. In this series the presence of tumor thrombosis of the renal vein or involvement of the perineural lymphatics apparently had little influence on the five year survival rate. However, Ladd and White considered the presence of venous invasion to be an unfavorable prognostic sign.

Gross and Neuhauser state that the improvement in survival rate of children with Wilms's tumors from 14.9 per cent in the years 1914 to 1930 to 32.2 per cent in the years 1931 to 1939 can be attributed to improvements in operative technic. One of the modifications adopted during the latter period was the utilization of a transperitoneal approach to permit early ligation of the renal pedicle. One can only speculate regarding the relative importance to the improved survival rate of the transperitoneal approach with early ligation of the renal vessels, and other improvements in operative technic which occurred simultaneously. It is quite

possible, too, that earlier recognition may have been an unrecognized factor in the improved survival rate.

The fact that multiple metastatic nodules of grossly similar size may appear simultaneously on the chest film indicates that a veritable shower of tumor emboli with a high percentage of "takes" can occur under certain circumstances. It is conceivable that such nodules appearing within a few weeks after operation represent tumor emboli resulting from the local trauma incident to nephrectomy. On the other hand, it is possible that such metastases represent tumor emboli which have occurred independent of the surgeon's intervention.

Theoretically, deep inspiration, and indeed normal respiration, may be considered to increase the risk of dissemination of any type of renal neoplasm, particularly those which invade veins (renal adenocarcinoma, carcinoma of the renal pelvis, Wilms's tumor), as a result of the up-and-down motion of the kidneys imparted by the diaphragm and the venous pulse engendered by the associated changes in intrapleural pressure. The physical activities of a small child are apt to be sufficiently strenuous to constitute a hazard of dissemination equally as great as that due to the handling of the kidney incident to nephrectomy. This observation may help to explain the better prognosis of patients with Wilms's tumor who are less than one year of age.

The available data indicate the frequency of venous invasion in Wilms's tumors and point out the association of venous invasion with a poor prognosis. The evidence for venous dissemination in these neoplasms is sufficiently strong and the results of Gross and Neuhauser with early ligation of the renal pedicle are sufficiently suggestive to justify early ligation of the renal vessels on specific therapeutic as well as on general surgical grounds. More clinical information must be accumulated, however, before the value of early pedicle ligation can be regarded as conclusively established.

The Tendency toward Lymphatic Spread. The difficulties in the histologic demonstration and the hazards of subsequent interpretation have combined to keep precise knowledge of intrarenal lymphatics at a minimum. The lymphatics within the kidney have been described by Rawson in a case in which permeation by carcinoma made the channels more apparent. He found that the lymphatic channels began blindly at two points, one, closely adjacent to Bowman's capsule, and the other just beneath the mucosa of the papilla. From these two origins, lymphatic networks arose which accompanied the arterial and venous supply of the kidney. The network in the medulla drained peripherally toward the arcuate vessels, while that from Bowman's capsule drained centrally toward the same vessels. The two channels apparently became confluent about the arcuate vessels. No lymphatics were demonstrable in the glomeruli, about the intertubular capillaries, or about the afferent or efferent arterioles. A close association between the large, thin-walled veins of the outer half of the cortex and the lymphatic channels of this area was noted. It was suggested that these veins were expansions of the interlobular veins and their tributaries and that the closely associated lymphatic and venous channels might form a regulatory system for fluid exchange.

Rouvière's classic monograph on the lymphatics indicates that: (1) the lymphatics of the perirenal capsule and perirenal fat converge at the renal hilus, joining with those of the renal parenchyma; (2) the renal parenchymal lymphatics

presence is associated with a poor prognosis. However, it cannot be inferred from these facts that renal vein invasion is the cause of the poor prognosis. Renal vein thrombosis may be interpreted as merely one other manifestation of an insidious neoplasm which is well advanced locally and perhaps systemically at the time of the initial diagnosis. That the presence of massive tumor thrombosis increases the risk of tumor embolism seems probable, but that such embolism is synonymous with tumor metastasis can be summarily denied.

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survival rate, it cannot be inferred that the particular feature is the actual cause for the reduced survival, the importance of venous invasion in the Wilms tumors being the one probable exception.

TECHNIC

In accord with the present trend toward a more radical surgical approach to the problem of cancer generally, it is not surprising to find that most of the recent changes in the treatment of renal tumors have been directed along similar lines. The present approach to the problem of renal tumors is based on the following principles:

(1) Adequate exposure;

(2) Minimal handling of the kidney, especially prior to ligation of the renal artery and vein;

(3) Intact removal of Gerota's fascia with the enclosed perirenal fat and kidney, and including the adrenal gland in the case of an upper pole neoplasm;

(4) Systematic dissection of the regional lymph nodes along the great vessels from the level of the diaphragm above to the level of the aortic bifurcation below;

(5) Removal of the entire ureter and an adjacent cuff of bladder, in the case of papillomatous tumor of the renal pelvis, with simultaneous dissection of the homolateral pelvic lymph nodes if there is evidence of one or more satellite tumors in the ureter.

The recent description of several different surgical approaches to the kidney has been an important development. In 1947, Sweetser described an incision which he employed with success in the removal of renal tumors. With the patient in the usual lateral kidney position an oblique lumbar incision is made between and parallel to the 11th and 12th ribs extending from the costovertebral angle across the ipsilateral rectus muscle to a point about midway between the umbilicus and the symphysis pubis. The incision is then extended upward close to the midline to the xiphoid process. The peritoneum is not opened. As advantages, the author cites preservation of the nerves supplying the abdominal muscles, excellent exposure of the renal pedicle, and the fact that the peritoneum is not opened.

In 1950 Nagamatsu described a dorsolumbar incision which is both extrapleural and extraperitoneal and in which the removal of short segments of the lower three ribs at their angles results in the formation of a retractable osteoplastic flap of the otherwise rigid lower thoracic cage, permitting access to the subdiaphragmatic space. Excellent exposure is afforded and neither the pleural nor peritoneal cavities need be entered.

In 1948 Mortenson reported the use of a thoraco-abdominal incision for the removal of a large renal tumor. Chute and Soutter were the first in this country to report the use of this exposure for the removal of renal tumors. The incision combines transthoracic and transabdominal exposures. With the patient in the lateral position an incision is made from the lateral margin of the rectus muscle at the level of the umbilicus, posteriorly, superiorly, and laterally over the 10th or 11th ribs to within 3 cm. of the dorsal midline. The pleural cavity is entered through the bed of the subperiosteally resected rib. The lung is maintained almost completely expanded. The diaphragm and abdominal muscles are incised

drain into lymph nodes adjacent to the aorta and inferior vena cava both above and below the level of the renal vessels; (3) the lymphatics of the perirenal capsule and perirenal fat communicate with the lymphatics of the adjacent organs, particularly those of the colon, liver, diaphragm, and adrenal. There is a paucity of studies on the incidence of regional node involvement in renal cancer.

Renal Adenocarcinoma: Albarran and Imbert found lymph node involvement in 60 (24 per cent) of 249 cases of renal carcinoma and Garceau found regional lymph node involvement in 11 (6.2 per cent) of 176 cases of renal cancer. These findings indicate that lymph node involvement is quite common in renal adenocarcinoma. Such data, however, are based for the most part on studies of patients with advanced renal cancer and are therefore of limited therapeutic value.

There are few studies regarding the incidence of regional node involvement at the time of operation. Snelling found regional node involvement in 3 of 28 carefully studied cases of renal adenocarcinoma subjected to nephrectomy. Chute's material provides a relatively complete picture in a small group of cases. The latter performed thoraco-abdominal nephrectomy on 38 patients with renal tumors, only 12 (31.6 per cent) of whom were free of either local extension or metastases at the time of operation. Seven cases had tumor thrombosis of the renal vein, 5 had pulmonary metastases, 2 had extension to the perinephric fat, and 4 had liver involvement (direct extension in 2 and metastases in 2). Positive nodes were encountered at operation in 11 cases and were removable in 6 cases. Nodes were removed in at least 7 other cases but were found to be free of metastases.

Present knowledge does little more than indicate that regional node involvement may occur in renal adenocarcinoma and that it is not rare. Determination of the incidence of such involvement must await further studies. Regional node invasion is undoubtedly associated with a diminished survival rate but its exact role in prognosis must await further clinical studies.

Epithelial Tumors of the Renal Pelvis: Regional node involvement occurs in epithelial tumors of the renal pelvis and is undoubtedly associated with a reduced survival rate. Specific information on these points, however, is not available.

Embryonal Tumors: No careful studies of the incidence of regional node involvement or of the influence of such involvement on prognosis have yet been made for this group of neoplasms. There have been enough casual observations, however, to indicate that node invasion is not rare.

Thus, for all three major groups of renal neoplasms (renal adenocarcinoma, epithelial tumors of the renal pelvis and embryonal neoplasms) there is:

(1) a variable tendency toward direct perirenal extension which is manifested not only by the gross and microscopic evidence of extension found at operation, but by the subsequent appearance of local recurrences;

(2) a variable tendency toward venous invasion evidenced by gross and microscopic studies of specimens obtained by nephrectomy;

(3) a definite but as yet undefined tendency for lymphatic involvement as evidenced by operative and postmortem studies.

It is impossible to estimate from the available data how often treatment failures can be specifically attributed to any or all of the above three features. Granting that the presence of any one of them is invariably associated with a diminished

constitute a threat to life. Ferris and Daut reported successful treatment of an epithelioma of the pelvis of a solitary kidney by electrocoagulation.

Embryoma of the Kidney. The present program of therapy for Wilms's tumor at Memorial Hospital is a modification of that established by the work of Ladd, White, Gross, and Neuhauser. Every child in whom the presence of an abdominal mass leads to a suspicion of Wilms's tumor is treated as an emergency surgical problem. Abdominal palpation is restricted to a minimum. The admitting physician, the pediatric resident, and the operating surgeon only are permitted to palpate the tumor. An emergency chest plate and an emergency intravenous pyelogram are done. If the chest plate reveals no evidence of pulmonary metastasis, if the bones show no changes suggesting metastatic neuroblastoma, if the intravenous pyelogram reveals the presence of a normal contralateral kidney, and if the general condition of the child does not contraindicate emergency surgery, the patient is taken immediately to the operating room where a nephrectomy is performed according to the principles outlined for renal adenocarcinoma. The modification of the Sweetser incision previously described has proved adequate for this purpose. In children the wide costal angle and the flexibility of the thoracic cage significantly reduce the thoracic barrier to adequate exposure. There is no contraindication to the use of a thoraco-abdominal incision in children, but because of potential orthopedic problems in later life resulting from rib resection, an intercostal approach should be employed. Immediately after operation and while the child is still under anesthesia, roentgen therapy is begun. With portals limited to the tumor bed it was found that metastatic abdominal disease developed outside the fields of irradiation in approximately 80 per cent of the patients. Accordingly, present policy is to irradiate the entire abdomen through a single anterior and a single posterior portal, delivering a dose of 2000 r to the retroperitoneal area in a period of about three and one half to four weeks, using the 1000 KV X-ray unit. Children tolerate this therapy remarkably well.

It is too early to evaluate the results of such surgical and radiation technics at this institution. It can be said, however, that there has been no demonstrable increase either in mortality or morbidity from the use of more extensive surgical procedures and immediate irradiation. Possibly none of the technics suggested will have any appreciable value in improving the survival rates for the different types of renal cancers. Only further experience can answer this question.

PALLIATIVE TREATMENT

In spite of major surgical efforts the majority of patients with renal cancer are doomed to die of their disease. For these patients and for those who are inoperable when they are first seen, one can hope only for palliation. The available technics are of limited value.

Renal Adenocarcinoma. Renal adenocarcinomas are, generally speaking, radioresistant. The major indication for palliative irradiation of the primary tumor is pain. Hematuria does not respond reliably to irradiation and, when severe, may justify nephrectomy in a hopelessly incurable patient. Metastases in soft parts may decrease considerably in size under appropriate therapy relieving such distressing symptoms as pain and hemoptysis. Bone metastases are apt to cause

in line with the skin incision opening the peritoneal cavity. Excellent exposure is afforded. Of 110 patients operated on by this technic (Chute), there was only one postoperative death and this could not be attributed to the particular incision employed. There were two serious complications, only one of which could be attributed to the use of the thoraco-abdominal approach.

The proponents of both the Nagamatsu technic and the thoraco-abdominal incision vigorously argue the merits of the respective procedures. Both incisions provide excellent exposure. The extrapleural-extraperitoneal feature of the Nagamatsu incision is cited as an advantage by its supporters, while the proponents of the thoraco-abdominal incision acclaim its intrapleural-intraperitoneal features. The opportunity to explore the peritoneal cavity and examine the homolateral lung and mediastinum is of particular value in patients with renal neoplasms.

At the present time at Memorial Hospital the following program is employed in the management of patients with renal tumors who have no evidence of distant metastasis:

Renal Adenocarcinoma. For renal adenocarcinoma nephrectomy is performed in accordance with the previously mentioned principles. The thoraco-abdominal incision is employed routinely, the abdominal portion of the incision only being developed until the nature of the lesion and its resectability have been determined. For patients in whom the use of the thoraco-abdominal incision seems unwise, a modification of the Sweetser incision is commonly employed. With the patient midway between the supine and lateral positions incision is made from the tip of the 10th, 11th, or 12th ribs anteriorly and inferiorly parallel with the spinal nerves to the midline. The underlying muscles are divided and the peritoneum opened. If exploration reveals a removable tumor, the incision is extended vertically to the xiphoid just far enough lateral to the midline to obtain both anterior and posterior rectus sheaths for the closure. The colon is reflected medially and inferiorly by dividing the peritoneum of the lateral gutter, and either the gastrocolic or hepatocolic ligament is divided depending on the side on which the tumor is located. On the left side the renal vessels can usually be identified and divided early by retracting the tail of the pancreas anteriorly and superiorly. On the right side retraction of the duodenum exposes the renal pedicle.

Epithelial Tumors of the Renal Pelvis. For tumors of this group nephrectomy is performed as for renal adenocarcinoma. In addition, complete ureterectomy with removal of a cuff of bladder adjacent to the ureteral orifice is performed through a supplemental lower abdominal incision, either at the time of nephrectomy (in which case the specimen can be maintained in one piece), or within 10 days thereafter. Complete dissection of the lymph nodes of the homolateral pelvis is performed if there is evidence of a ureteral tumor. Although such a procedure may be somewhat radical for benign papilloma of the renal pelvis, the impossibility of making an absolute diagnosis at the time of operation, the fact that the first chance to cure a cancer may be the last (and is certainly the best), and the unchanged morbidity and mortality resulting from such radical procedures in comparison to conservative measures, justify such an approach.

The conservative surgical approach to certain benign tumors of the ureter suggested by Vest should be reserved for patients in whom the reduction in total renal function occasioned by unilateral nephrectomy would be such as to

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marked discomfort which can be relieved for brief periods by irradiation. Occasionally, evidence of calcification in a previously osteolytic bone lesion develops after the completion of roentgen therapy. For soft part metastases a tumor dose of 3000 to 3500 r in three to four weeks and for bone metastases a tumor dose of 2000 r in two weeks, are commonly delivered using the 1000 KV unit.

The occasional reduction in size or apparent disappearance of metastatic deposits following removal of the primary tumor has already been mentioned. It seems hardly to occur with sufficient frequency to justify advising nephrectomy in all such cases. It has been suggested that nephrectomy might increase the radioresponsiveness of metastases but there is no evidence to prove or disprove such a thesis. The incidence of apparently solitary metastases in the presence of renal adenocarcinomas justifies the concept that an otherwise hopeless situation may be salvaged occasionally by an aggressive surgical approach in carefully selected cases.

Combinations of roentgen therapy with intravenous nitrogen mustard therapy have failed to produce any improvements which could not be accounted for by roentgen therapy alone. Whether or not the use of various steroid hormones can be considered to have any therapeutic rationale in otherwise hopeless renal cancers, current trial at this institution has as yet failed to produce any objective evidence of improvement. Evaluation of the methods of palliation is made difficult in renal adenocarcinoma by the occasional prolonged survival of an untreated patient with widespread disease.

Epithelial Tumors of the Renal Pelvis. The inoperable, recurrent, and metastatic forms of carcinoma of the renal pelvis are extremely radioresistant. Transient relief of pain is usually the most that can be obtained by irradiation.

Embryonal Tumors. With Wilms's tumors local recurrences and pulmonary metastases may melt away within a matter of days under the influence of radiation therapy but such remissions rarely last more than three to four months. The recurrences following such remissions may retain their original radiosensitivity, but radiation damage to the adjacent normal tissues constitutes a limiting factor in re-treating the patients. Because of the high incidence of bilateral pulmonary metastases, treatment of any pulmonary metastasis is ordinarily accomplished by irradiating the entire chest through a single anterior and a single posterior port and delivering a tumor dose of 1500 r in three weeks using the 1000 KV unit. Combinations of nitrogen mustard therapy and irradiation in the treatment of recurrent or metastatic Wilms's tumors seem to have little if any superiority over irradiation alone.

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Surgery of the Large Arteries

NORMAN E. FREEMAN, M.D.

WITH RUTHERFORD S. GILFILLAN, M.D., TOM M. FULLENLOVE, M.D., AND FRANK H. LEEDS, M.D.

INTRODUCTION

SINCE HEMORRHAGE is the most serious result of injuries, whether accidental or operative, wounds of the large arteries and methods of controlling bleeding have from the earliest times excited the interest of surgeons. Halsted, in 1912, wrote: "One of the chief fascinations of surgery is the management of wounded vessels; the avoidance of hemorrhage. The only weapon with which the unconscious patient can immediately retaliate upon the incompetent surgeon is hemorrhage. If he bleeds to death it may be presumed that the surgeon is to blame; whereas if he dies of infection or shock or from an unphysiological operative performance, the surgeon's incompetence may not be so evident." It is interesting to note that the reputations of the three surgeons whom Garrison selects as the greatest of all time—Ambrose Paré, John Hunter, and Joseph Lister—are founded chiefly or in large part on the use of the ligature.

The surgery of the large arteries may conveniently be divided into three periods. The first period may be called the era of ligation. The goal of this period was the obliteration of the artery, either in the treatment and prevention of hemorrhage or to still the pulsations of blood within an aneurysmal sac. The era of ligation extended well into the period of antiseptic surgery and reached its zenith in the classical monograph by Ballance and Edmunds, *Ligation in Continuity*, which was published in 1891. The technic of surgery had not yet been sufficiently developed to permit adequate exposure. The authors wrote: "In sufficiently exposing, for example, the third part of the subclavian or the external iliac for the operation of double ligature and division, much more disturbance of the part must ensue and far more risk must be run of injury in the one case to the pleura and the fact of an axillary aneurysm and in the other to the peritoneum and the fact of an inguinal aneurysm, than if the sheath of the artery were only exposed enough to allow an opening to be made in it just sufficiently large to admit the aneurysm needle; for to this amount alone should the sheath be stripped. Indeed, the argument that the Celsian method diminishes the risk of hemorrhage by insuring that no part of the artery above the upper and below the lower ligature is deprived of the nourishment it receives from its sheath, ignores the proper way of ligating an artery in continuity."

With the introduction of asepsis, hemostatic forceps, and the principle of exact hemostasis with ligation of all bleeding points so as to avoid the need of drainage or packing, the principle for which the studies of Halsted are mainly responsible, the second era of the surgery of the major arteries may be considered to have

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been introduced. This era may be called the definitive period. With the aid of modern anesthesia, blood transfusions, aseptic technic and the use of the antibiotics, together with the development of surgical technics, adequate exposure of major blood vessels throughout the body has been made possible. The first intrasaccular obliteration of an arterial aneurysm was performed by Matas in 1888. With further understanding of the physiology of the circulation, the definitive surgery of major arteries has been greatly extended. In the surgical treatment of aneurysms and arteriovenous fistulas resulting from wounds of the major arteries in World War II, the incidence of gangrene in more than 1,000 cases was less than 0.5 per cent.

The third period in the surgery of the large arteries, the restorative or reconstructive era, has proceeded in its development almost simultaneously with the definitive era. It was Matas who first suggested the restorative and reconstructive endo-aneurysmorraphy. Carrel had published his well known method of end-to-end anastomosis of blood vessels in 1902, and demonstrated the practicability of the use of blood vessel grafts. The brilliant results in the surgical treatment of congenital cardiovascular disorders achieved by Gross, Crafoord, Blalock, and Potts, and the venous shunt operations devised by Blakemore in the treatment of portal hypertension, illustrate some of the early achievements of this reconstructive era. It is safe to predict that many new advances will come with this orientation toward restoration of the anatomic and physiologic function.

STRUCTURE AND FUNCTION OF ARTERIES

In most parts of the body, the arteries are enclosed in a sheath formed of connective tissue which, in its turn, is continuous with the connective tissue of the neighboring structures. The outer coat of arteries is connected to the sheath by filaments of the same tissue, but so loosely that when the vessel is cut across its ends readily shrink some way within the sheath. Some arteries lack sheaths, those, for example, which are situated within the cranial cavity.

Independently of this sheath, arteries have usually been described as formed of three coats or tunicae: the intima, the media, and the adventitia. The structure of the larger arteries differs somewhat from that of the smaller vessels. Thus, if the common carotid be compared with the radial, it will be seen that the wall of the larger vessel is proportionately thinner, and that while in the radial the demarcation of the inner coat from the middle is clearly marked by the fenestrated membrane of Henle, in the carotid the distinction is not so clear on account of elastic membranes being present in greater numbers in the middle coat and extending into the subendothelial layer of the inner coat.

The intima may be raised from the inner surface of the artery as a fine, transparent, colorless membrane, elastic but easily broken, especially in the circular or transverse direction, so that it cannot be stripped off in large sheets. The intima, which is composed chiefly of endothelial cells and connective tissue, has an extraordinary capacity for regeneration. It is commonly corrugated with fine and close longitudinal wrinkles, caused by the contracted state of the artery after death. If the artery is fixed when it is distended at a pressure equivalent to that to which it is normally exposed during life, the intima is no longer corrugated.

The intima, which is highly elastic, is covered with a single layer of endothelium. It was formerly considered that damage to the intima always resulted in thrombosis. Recent studies, however, have shown that even extensive damage to the intima of a major artery *does not lead to thrombosis unless there is some* interference with the volume flow of blood traversing the artery at the site of injury.

Although it is generally advisable to suture arteries intima to intima, the experience of Gross, Crafoord, and Potts has shown that this is not necessarily so, especially where there is a rapid flow of blood across the suture line.

The middle coat or media of large arteries is composed for the most part of smooth muscle, but as the size of arteries increases, relatively more elastic tissue is found in this layer. Unlike the intima, the media possesses little power of regeneration, and damage to it is repaired by fibrous scar tissue. This characteristic is of primary importance since it is only through the presence of smooth muscle or elastic tissue that the arteries are capable of withstanding the pressure of the blood within them.

The external layer or adventitia is composed largely of layers of elastic tissue fibers running longitudinally and set together by a few strands of white fibrous tissue. The adventitia contains the nutritive vessels of the arterial wall and the major motor nerve fibers. According to Horsley, "All of the larger vessels are provided with minute nutrient vessels which usually come from some neighbouring artery and are distributed in the adventitia of the blood vessel. They are called vasa vasorum. Lymphatics and nerves are also found in the outer coats of the blood vessel. The plexus of nerves that surrounds the arteries is particularly abundant. Small nerve fibers from this plexus enter the media and are distributed among the muscle cells. These nerve fibers are chiefly motor in function and are a part of the great vasomotor system. Sensory nerves undoubtedly occur quite constantly accompanying the vessel wall. This is frequently demonstrated in operations under a local anesthetic, when the clamping of a blood vessel will cause pain even though the surrounding tissue appears to be free from sensation."

The adventitia is of prime importance in the arrest of hemorrhage since the blood is caught in its meshes when the artery is torn or divided, and from it springs most of the new tissue which organizes the repair of the vessel. Because of this capacity of the adventitia to promote clotting by forming a mesh, it is particularly important to avoid carrying any portion of this layer into the lumen of the blood vessel during the performance of arterial sutures. The careful trimming away of the adventitia has come to be recognized as the first step in the performance of a successful vascular repair.

Even though it is apparently the least substantial portion of the vessel wall, the adventitia has great tensile strength, and it is largely to this layer that the blood vessels owe their capacity to withstand relatively enormous pressures. For instance, Winternitz found that the healthy carotid artery of a dog would rupture only when 20 times normal pressure was put on it. When the adventitia is stripped, however, the artery bursts when the pressure is raised to only a fraction of this amount.

The adventitia is also of great importance to the surgeon who is called on to mobilize arteries over a considerable distance or to ligate the vessel. In the first

place, since the nutrition of the media and adventitia is largely derived from the vasa vasorum, extensive mobilization may so impair the vascularity of the wall that healing may fail to take place at the suture line. In the ligation of large arteries, sufficient force may be applied to rupture the intima and media and yet, as Ballance and Edmunds showed, the adventitia alone may be able to withstand the force of the blood pressure. Once the adventitia is stripped, however, the tensile strength of the vessel is greatly diminished so that rupture may take place with only moderate traction, especially if exerted by a slender thread.

The contractility of large arteries determines to a considerable extent the outcome following injury. It is well known, for instance, that complete division of the vessel, especially by a crushing or tearing injury, may result in little hemorrhage in comparison to that observed following a clean division by a sharp instrument. Retraction of the vessel walls, together with incurving of the traumatized adventitia, effectively seals the lumen. Incomplete severance of the vessel is associated with far more serious hemorrhage, since the two ends of the vessel are unable to contract. The following experiment of Ballance and Edmunds is also of interest in this respect: "If in the artery while distended with water a longitudinal incision be made, the water will spurt out, and it will be seen that the aperture is very wide, nearly circular, in fact. On the other hand, if a transverse incision is made, it will be seen that the water escapes in a flat sheet and that the aperture is linear. The explanation of the difference seems to be that the transverse contractility which exists in a distended artery widens out a longitudinal slit, but there is little or no longitudinal contraction to do the same for the transverse slit."

The adaptability of the arterial system to meet the tissue demand for blood is remarkable. It was John Hunter who first demonstrated the effectiveness of collateral circulation in a case of popliteal aneurysm. The increase in the collateral circulation represents a true hypertrophy as pointed out by Sir Thomas Lewis, Thoma, and Nothnagel. The tortuosity observed in collateral blood vessels is therefore due to the increase in length, which necessarily accompanies the increase in diameter. As pointed out by William Hunter in his *Observations on Aneurysms*, "A river becomes longer because it digs a winding channel for itself, whereas an enlarged artery becomes winding because it is lengthened and therefore cannot preserve its straight course." The dilatation of the artery supplying an arterial venous fistula and the tortuosity of collaterals in the presence of this lesion are well known, but the exact mechanism by which this change in the structure of the vessels is brought about is still to be discovered.

LIGATION OF ARTERIES *

"Although the ligation of arteries has now been practised for upwards of 20 centuries, the best method of performing the operation still remains one of the great questions of surgery. The reason for this is not far to seek. It lies in the frequency in which, in this and every age, hemorrhage has followed the operation.

* J. Collins Warren gives a comprehensive review of the history of the ligature in his monograph entitled *The Healing of Arteries*, published in 1886. See also Matas in Keen's *Surgery*, Vol. V, page 115.

The introduction of antiseptic surgery has no doubt diminished the danger, but it must not be forgotten that if the arterial wall be injured, hemorrhage may occur in a perfectly aseptic wound; and, in fact, it is well known that many cases of hemorrhage have occurred since the introduction of the Listerian method 20 years ago." Such was the picture presented by Ballance and Edmunds in 1891. As a result of their extensive investigation, they concluded: "From these experiments it is clear that arteries can be permanently occluded without the rupture of any of their coats. To effect this with certainty it is essential to employ a suitable ligature, a suitable knot tied with appropriate force, and to preserve the strictest asepticity." Ballance and Edmunds were dealing with the ligation of arteries in continuity. However, as Reid and Andrus point out: "Any ligature of an artery, whether it partially or completely occludes the lumen, leads to death of the enclosed segment of vessel." This result is to be anticipated since sufficient pressure must be employed in tying the knot to occlude the artery against the head of arterial pressure within it. Such pressure, clearly, would be more than sufficient to occlude the vasa vasorum, which are maintaining the viability of the arterial wall. Since the artery is contractile, as shown by the distance each end contracts on being severed (Holman, 1942), the artery at the site of a ligation in continuity is under tension. This tension exerted on the zone of necrosis produced by the ligature may cause the arterial wall to give way, with resultant hemorrhage. Pearse and Holman have shown that at least part of the force of the column of blood is taken up in the elastic recoil of the completely divided artery.

In his treatise on *The Healing of Arteries,* J. Collins Warren in 1886 wrote as follows: "Provided the ligature be adjusted so as to obstruct permanently the flow of blood through the vessel, it is manifest from the observations which have been described that a destruction of a certain portion of the vessel wall and a retraction of the end of the vessel must eventually take place, no matter what the nature of the material may be or how it be applied. The prime object, therefore, to be obtained is to employ such methods as will interfere as little as possible with the natural sequence of events which follow one another during the process of repair under the most favorable conditions."

Of course, in smaller vessels or in vessels containing a larger proportion of muscle in the wall, the results of ligation are uniformly good, except perhaps in the presence of infection. For the closure of the great arteries, however, and of even lesser ones in the presence of infection, the use of the ligature is hazardous since tissue necrosis is inevitable; some more effective method is desirable.

Murray describes the method of obtaining complete closure of the vessel without interference with the process of repair, namely the suture closure of the divided vessel. The fact that arterial wounds, whether longitudinal or transverse, heal readily when sutured, and the fact that end-to-end anastomoses of arteries, even those as large as the thoracic aorta, are usually successful, demonstrate clearly that the arterial wall remains viable when sutured and that the process of repair is not hampered. The division of the ductus arteriosus with suture of the open end, described by Gross, has been performed many times with uniform success. Murray and Janes and Swan and Harper have demonstrated in dogs the healing of the sutured end of the abdominal aorta, and Blalock and Park, in their studies on experimental constriction of the aorta, closed the divided thoracic

aorta with sutures. This operation has frequently been successfully performed in man (Claggett; Stephens). This type of suture closure has been found especially useful in the presence of marked degenerative changes in the arterial wall, where the rigidity and calcification of the vessel make it hazardous or impossible to obtain closure by means of a ligature. In patients who have had long-standing arteriovenous fistulas with great dilatation of the proximal artery and a weakening of its wall, an effective closure has been readily accomplished.

In order to obtain a stronger closure in vessels of unusual size, for example the abdominal aorta, it is possible to divide the vessel in an oblique direction, as shown in Fig. 2. The end of the vessel is then closed with a running stitch. The force of the column of blood during the systolic thrust is then spread out over a wider portion of the vessel wall. Such a closure was effected in a patient with an aneurysm of the abdominal aorta due to trauma, but the patient died of tissue ischemia within 36 hours, before the healing of this type of closure could be tested.

The point at which the closure of an artery should be performed is of some significance. According to Holman (1944) a large artery should be ligated just distal to a large collateral branch so that the full force of the arterial pulsation in the main ligated artery is directed into this branch. Again, the distal ligature of a divided artery should be placed just proximal to a large collateral branch so as not to leave a blind segment between the ligature and the collateral. According to Holman's experimental work, the pressure forcing blood through the collateral, both above the closure and below it, is greater provided there is no blind pouch which may serve to dissipate the force of the arterial pulsation. Of possibly even greater significance is the importance of not leaving a blind pouch, which would favor the development of intra-arterial thrombosis, since the extension of such a thrombotic process might occasion the closure of collateral vessels.

SURGICAL TECHNICS

The technic of surgery at present represents the accumulated experience and wisdom of generations of surgeons. It is based on, and changes with, developments in all of the basic fields of medical science and technology. For example, before the advent of anesthesia, it was essential to "get in quick and get out quicker." Then manual dexterity and a complete familiarity with anatomy were the chief qualifications for the surgeon.

Even with the advent of anesthesia, the problem of time was not solved, since it was soon recognized that prolonged operations left the patient in an "exhausted" state, and the well known adage, "the operation was successful but the patient died" came into being. Understanding of some of the mechanisms of surgical shock greatly influenced the development of surgical technic. It was soon recognized that more lives were lost through haste than were saved by speed. Blood transfusions, the administration of fluids, and the general principles of preoperative and postoperative surgical care allowed the surgeon more and more time for the performance of his technical task. Antisepsis, asepsis, and finally the use of the antibiotics, together with a better understanding of the fundamental principles of tissue physiology and healing, extended the field of reparative surgery. Finally,

technical improvements in anesthesia and the ability to bring light into dark places have opened almost the entire body to the explorations of the surgeon.

The precise and gentle handling of tissues constituted one of Halsted's great contributions to surgical technic, and in no field more than in the surgery of arteries is this principle predominant. Blood vessels do not idly tolerate insult or injury. To rough handling they respond, like an angry child, by spasm. With injury, the result is thrombosis or hemorrhage. The proper attitude of the surgeon toward a major artery should be that of Izaak Walton toward the frog which he is impaling on his hook, "handle him as though you loved him." Respect and consideration are the foundations of such love, and if to these can be added "adequate control," a happy union can be anticipated.

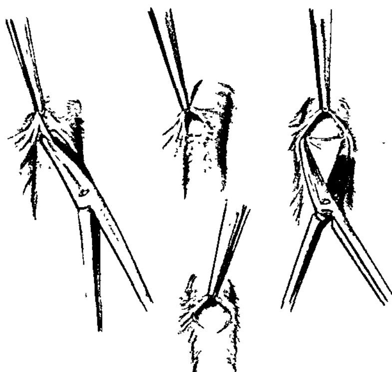


FIG. 1.—The use of sharp dissection to free an artery from its sheath.

Sharp dissection is the cornerstone of surgery of arteries. As does all smooth muscle, the arterial wall responds to stretching by spasm—the well known traumatic segmental arterial spasm of Kuttner and Baruch. To other forms of trauma it is physiologically passive, but to tension, as Kinmonth has recently shown, the response is myogenic contraction, a condition extremely difficult to overcome. The fact that the outer coats of arteries are connected to their sheaths by filaments of connective tissue makes sharp dissection a pleasure. As shown in Fig. 1, a single cut in the right place frees the artery from its moorings and establishes a plane of cleavage unsurpassed except, possibly, by that between the intima and the contents of the vessel. Control can readily be established by the procedure

illustrated in Fig. 2. A curved hemostat gently inserted beneath the artery is used to draw about the vessel a segment of rubber tubing. Not only can this tubing be used for control by compression with a curved clamp, as shown in Fig. 2, but it can serve as a mechanism for gentle traction in order to disclose the attachments of the main artery and its branches. Figure 3 illustrates a technic which has been found useful in the ligation of branches of the major vessels. First of all, the plane of cleavage is established, and at this point it may be necessary to incise the fascia parallel to the branch but at an angle to the major artery. Then by means of a small curved hemostat, a fine, nonabsorbable ligature can be drawn about the branch and tied close to the parent vessel. The distal end is then clamped and the branch divided, leaving a margin of 2 to 3 mm. It should be emphasized that fine silk or cotton is the preferred suture, since its tensile strength is sufficient, and a heavy ligature, because of its very bulk, may be torn off.

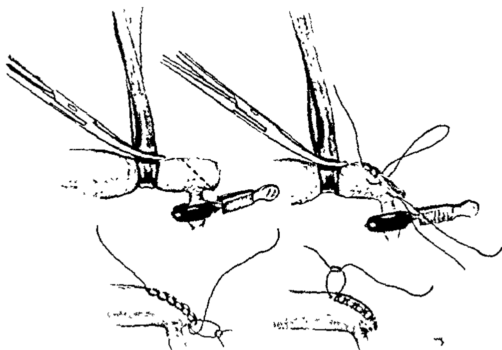


FIG. 2.—Prophylactic hemostasis by using a segment of rubber tubing compressed and held by a curved clamp, bulldog clamp on a large collateral.

At this point an additional reason for sharp dissection may be discussed. There is an abrupt difference in tensile strength between a large artery and its branch. A force sufficient to "clear" a major vessel will often shear off a small branch, and, at the same time, the force necessary to free a branch will be insufficient to disclose the major artery. Although it is not difficult with proper exposure, light, and suction to grasp the end of a divided vessel with a hemostat, when a branch is torn off a major artery, it leaves a tangential wound in the arterial wall. There is immediate extravasation of blood beneath the adventitia which obscures the opening into the lumen. Under such conditions, safe closure can be effected only

by suture of the arterial wall. As in the closure of a needle hole in the wall of a major vessel (Fig. 4), a figure-of-eight stitch has been found to be quite satisfactory.

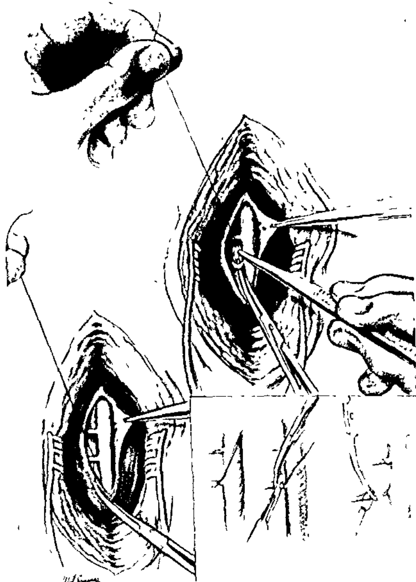


FIG. 3.—Technic for ligation of branches of a major blood vessel.

One further point in the specialized technic of surgery of the arteries should be stressed. The integrity of the vessel takes precedence over the loss of blood. With present-day methods of transfusion, blood banks, and the availability of intravenous infusions, blood volume can be replaced. To restore the continuity of blood vessels which have been torn or in which thrombosis has occurred is difficult or impossible. Injury of the intima is not the only factor which determines thrombosis. Figure 5 illustrates the condition of the intima in the carotid artery of a dog six days after trauma. This injury was produced by striking the vessel

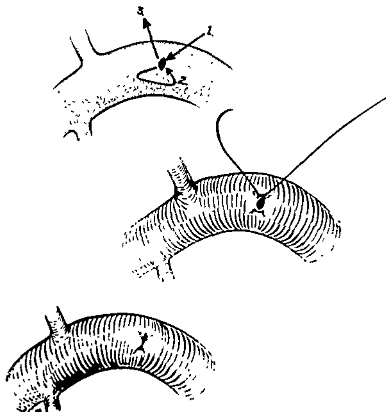


Fig. 4.—Closure of a needle hole in the wall of a major blood vessel by a figure-of-eight stitch of a fine nonabsorbable suture.

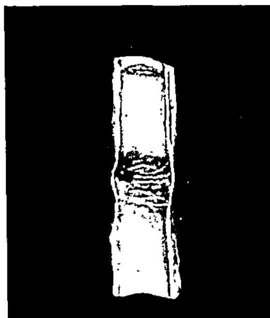


Fig. 5.—The carotid artery of a dog six days after trauma, showing extensive intimal damage and minimal thrombosis.

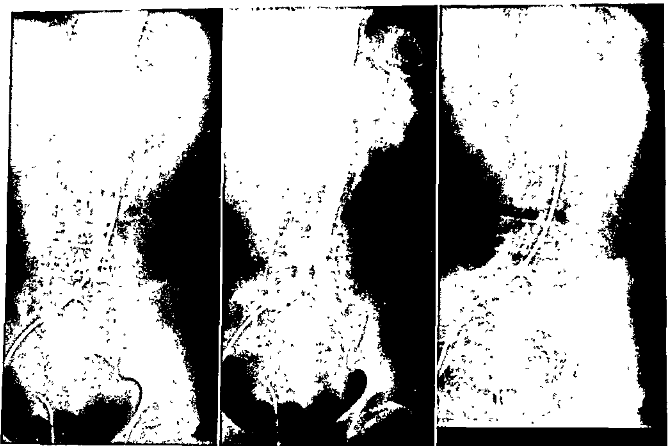


Fig. 6.—Aortogram obtained by injection of 70 per cent diodrast through a ureteral catheter inserted by way of the right femoral artery.

(Freeman, N. E., and Miller, E. R.: *Ann. Int. Med.*, 30:330, 1949.)

repeatedly with a blunt instrument in an unsuccessful attempt to produce arterial spasm. Although the intima was destroyed over a distance of 1 cm., thrombosis did not result as long as the flow of blood was unimpeded. This observation confirms that of Smith. However, when the circulation was obstructed by means of temporary occlusion of the vessel with a bulldog clip, thrombosis did occur. Intravascular thrombosis appears to depend not only on intimal injury but also *on reduction in volume flow of blood across the traumatized area. This observation* is in keeping with the investigations of Johns and Shumacker and Lowenburg on the percentage of patent vessels following various types of arterial and venous anastomoses. The greatest success is obtained in those cases in which there is a large volume flow of blood across the suture line.

ARTERIOGRAPHY

Introduction

Although much information concerning the location and character of large arteries can be gained by palpation of the peripheral pulses, the major arteries of the abdomen and thorax and numerous arteries of the extremities are not accessible to the examiner. By means of oscillometry, plethysmography, and skin temperature measurements, additional information can be acquired as to the circulatory capacity and competency. In the surgery of large arteries, however, nothing can take the place of visualization. As developments in surgery of the abdomen, urinary tract, head, and thorax have been aided by radiography, so advances in vascular surgery may be expected to develop with visualization of the blood vessels after the injection of contrast media. At the present time, surgeons would hesitate to open the abdomen without a gastro-intestinal series or barium enema. Thoracic surgeons have found bronchography increasingly significant in the surgery of the lung. Pyelography, either retrograde or excretory, is indispensable before surgery of the urinary tract. It can confidently be predicted that arteriography will be *of as much assistance in the development* of surgery of the large arteries as contrast visualization has proved to be in other fields.

Historical

Sicard and Forestier were the first to visualize the blood vessels of the human extremity by injection of radiopaque material. Their work in France was followed in the same year by that of Berberich and Hirsch in Germany and by *Brooks in this country. The contributions of Dos Santos established the usefulness* of angiography as a diagnostic method.

Physiology

Contrast visualization depends on the presence of the contrast medium in sufficient quantity and concentration to cast a shadow during the period of radiographic exposure. The problem in arteriography is complicated by the fact that the direction of flow is outward from the heart and that the organ to be visualized is already full of fluid. Again, the volume flow varies with the caliber of the arteries and, for the peripheral vessels, is dependent, at least in part, on

the degree of vasoconstrictor conus. What is required, therefore, is a "bolus" of the contrast medium which will pass through the vessels during the time of exposure. Finally, since the contrast material is injected directly into the circulation, it is carried to the nutrient capillaries where it comes into close contact with the tissues. Ideally it should be nonirritating, nontoxic, and readily excreted from the body. It should be sufficiently concentrated and should have sufficiently high molecular weight so that the volume of fluid to be injected is small. Although admittedly the perfect contrast medium for arteriography has yet to be developed, there are several now available which have been widely employed, and the indications for their use will be discussed.

Arteriography of the distal parts of the extremities can easily be satisfactorily obtained by injection of the contrast medium into the main artery at the root of the limb. Sufficient concentration of the dye can be achieved by temporary obstruction of the artery proximal to the site of injection. Visualization of the abdominal aorta by direct puncture below the 12th rib was first described by Dos Santos and has been extensively used by Nelson, Doss, and Wagner. Radiography of the thoracic aorta was accomplished by Blakemore by means of a needle inserted directly into this structure. More recently Hoyos and Del Campo have described a method for the introduction of 30 cc. of 70 per cent diodrast directly into the aorta by way of an 18 gauge needle in order to visualize the thoracic aorta and coronary vessels. Farinas, in his attempts at abdominal aortography, was the first to pass a catheter up one of the femoral arteries into the abdominal aorta. The radiopaque material was then injected through this catheter. A modification of this technic has recently been described by Goodwin.

In order to visualize the more centrally placed arteries, the contrast medium may be injected in a retrograde fashion. By the injection of a large quantity, up to 50 cc., of the contrast medium through a large needle (13 gauge) it has been possible to obtain excellent visualization of the arteries at the root of the limb and the thoracic aorta and its branches. This technic has been especially useful in the visualization of coarctation of the aorta and patent ductus arteriosus. It has been shown in the experimental animal (Farinas) that the injection, to be successful, must overcome, first, the inertia of the blood flow, and, second, the blood pressure. By means of the Valsalva maneuver (forced excretory effort against the closed glottis) the cardiac output can be reduced with a significant fall in blood pressure. Figure 7 illustrates the effect of the Valsalva maneuver on the blood pressure in a patient during this procedure. The pressure was measured by means of a strain gauge manometer connected with a needle inserted into the femoral artery.

The radiographic visualization of specific organs has been accomplished by Bierman and his associates by means of a catheter introduced through the brachial or femoral artery. This technic may find its greatest field of usefulness in the investigation and chemotherapy of individual viscera, but it is designed specifically for a certain structure and not the vascular tree. Figure 8 is an arteriogram of the liver and spleen with the tip of the catheter inserted into the celiac axis after passing through the brachial artery.

repeatedly with a blunt instrument in an unsuccessful attempt to produce arterial spasm. Although the intima was destroyed over a distance of 1 cm., thrombosis did not result as long as the flow of blood was unimpeded. This observation confirms that of Smith. However, when the circulation was obstructed by means of temporary occlusion of the vessel with a bulldog clip, thrombosis did occur. Intravascular thrombosis appears to depend not only on intimal injury but also on reduction in volume flow of blood across the traumatized area. This observation is in keeping with the investigations of Johns and Shumacker and Lowenburg on the percentage of patent vessels following various types of arterial and venous anastomoses. The greatest success is obtained in those cases in which there is a large volume flow of blood across the suture line.

ARTERIOGRAPHY

Introduction

Although much information concerning the location and character of large arteries can be gained by palpation of the peripheral pulses, the major arteries of the abdomen and thorax and numerous arteries of the extremities are not accessible to the examiner. By means of oscillometry, plethysmography, and skin temperature measurements, additional information can be acquired as to the circulatory capacity and competency. In the surgery of large arteries, however, nothing can take the place of visualization. As developments in surgery of the abdomen, urinary tract, head, and thorax have been aided by radiography, so advances in vascular surgery may be expected to develop with visualization of the blood vessels after the injection of contrast media. At the present time, surgeons would hesitate to open the abdomen without a gastro-intestinal series or barium enema. Thoracic surgeons have found bronchography increasingly significant in the surgery of the lung. Pyelography, either retrograde or excretory, is indispensable before surgery of the urinary tract. It can confidently be predicted that arteriography will be of as much assistance in the development of surgery of the large arteries as contrast visualization has proved to be in other fields.

Historical

Sicard and Forestier were the first to visualize the blood vessels of the human extremity by injection of radiopaque material. Their work in France was followed in the same year by that of Berberich and Hirsch in Germany and by Brooks in this country. The contributions of Dos Santos established the usefulness of angiography as a diagnostic method.

Physiology

Contrast visualization depends on the presence of the contrast medium in sufficient quantity and concentration to cast a shadow during the period of radiographic exposure. The problem in arteriography is complicated by the fact that the direction of flow is outward from the heart and that the organ to be visualized is already full of fluid. Again, the volume flow varies with the caliber of the arteries and, for the peripheral vessels, is dependent, at least in part, on

CONTRAST MEDIA

Sodium iodide in 80 per cent solution casts a dense shadow but it is quite irritating, so that a general anesthesia is necessary when it is employed. It may also be toxic since 2 patients in whom it was used developed a low grade fever, and in one of these patients impairment of renal function was noted. Sodium iodide is therefore recommended only for direct aortography, when it is introduced through a needle inserted directly into the aorta.

Thorotrast is nonirritating when injected into the arterial tree and produces no spasm of the peripheral vessels. Beautiful arteriograms are attainable with it. It has, however, two major drawbacks—it is not excreted by the body and is taken up by the endothelial macrophages, chiefly those of the liver and spleen, where it remains permanently.

Figure 9 is a roentgenogram taken one year after the injection of 100 cc. of 20 per cent thorium dioxide, soluble, intra-arterially. The dense outline of the liver and spleen results from the persistence of this element in these organs.



FIG. 9.—Roentgenogram of the upper abdomen one year after the injection of 100 cc. of 20 per cent thorium dioxide, showing the dense outline of the liver and spleen resulting from retention of the contrast media by endothelial macrophages of these organs.

A second major drawback to the use of thorotrast stems from the possibility of extravasation of this material at the time of injection. Figure 10 illustrates the persistence of the contrast medium in soft tissues below the groin in a patient who received an injection of 20 cc. of 25 per cent thorium dioxide, soluble, into the perivascular tissues of the right groin six years earlier. Complications of

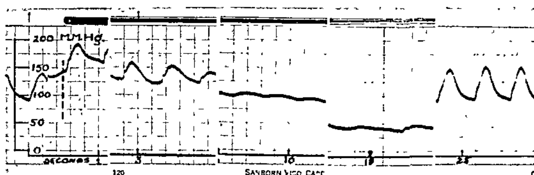


FIG. 7.—Arterial pressure tracing: strain gauge recording of femoral blood pressure variations during the Valsalva maneuver. The dotted line shows the point of commencement of expiratory effort following maximal inhalation. Note the drop in total pressure and pulse wave during 20 second interval of expiratory effort against a closed glottis. The last frame indicates the temporary overshoot of pressure following release.

(Freeman, N. E., et al.: *Ann. Surg.*, *130*:398, 1949.)

FIG. 8.—Hepatic arteriogram obtained by injection of 10 cc. of 70 per cent neo-iopax through a 150 cm. No. 9 catheter introduced through the brachial artery until its tip lay in the celiac axis.

(Bierman, H. R., et al.: *J. Nat. Cancer Institute.*)

sation of heat in the distribution in the blood vessel into which it is injected. Within a minute or more, nausea and, at times, vomiting are produced in about 30 per cent of the patients. Occasional deaths following its administration have been reported. Pendergrass collected 27 incidences out of more than 200,000 injections. It is essential, therefore, to test the patient for sensitivity to diodrast before intravascular administration of this drug.

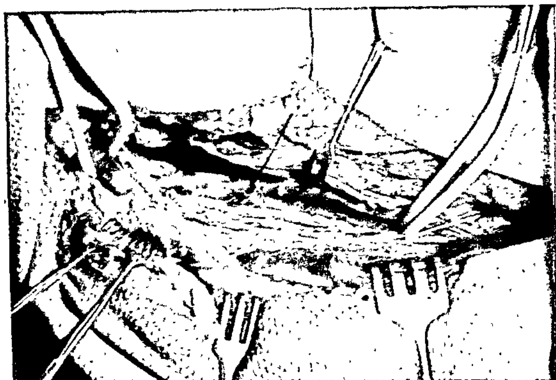


Fig. 11.—Operative findings in a patient six years after extravasation of 20 cc. of thorotrast about the femoral artery. The superficial and profunda femoris arteries were densely bound down by the scar tissue. The dilated common femoral artery (tube surrounding the vessel on the left side) can be seen entering the involved area. The entire mass was resected by sharp dissection.

(Courtesy of Veterans Administration Hospital, San Francisco.)

Diodrast Sensitivity Test. One drop of 35 per cent diodrast is placed in the conjunctival sac and 1 cc. under the tongue. At the end of five minutes the patient is instructed to swallow the diodrast which is in the mouth in case no edema about the base of the tongue has been produced. At the end of 15 minutes the conjunctival sacs of the two eyes should be observed to determine the evidence of edema or inflammation. At the same time it can be noted whether or not urticaria has been produced about the oral cavity or pharynx.

Thirty-five per cent diodrast is moderately irritating and will produce spasm of the smaller blood vessels. In the extremities a successful injection is frequently followed by blanching of the skin with subsequent mottling. Perivascular extravasation is associated with severe local pain and tenderness, but the diodrast is rapidly absorbed and disappears within the course of 24 hours. Figure 15 is a roentgenogram taken immediately following extravasation of diodrast into the

this nature were reported in 13 cases in 1949. In 11 of the patients the thorotrast persisted about the carotid vessels and in 2 patients about the brachial artery. There were no deaths. Figures 11 and 12 illustrate the findings in the patients after an extravasation of thorotrast about the femoral artery in the right inguinal region. The superficial and profunda femoris arteries were densely bound down and compressed by the scar tissue. The dilated common femoral artery can be seen entering the involved area. The entire mass had to be resected by means of sharp dissection. The major arteries were found to be so friable that suture was



FIG. 10.—Roentgenogram showing the persistence of thorotrast in the soft tissues below the groin six years after extravasation of 20 cc. of 25 per cent thorium dioxide into the perivascular tissues about the femoral artery.

impossible so that the profunda femoris had to be ligated and the involved segment of the superficial femoral artery replaced by a vein graft. Figure 13 shows the histologic appearance of the tissues which were removed, and Fig. 14 is an autoradiograph illustrating the highly radioactive character of the thorium six years after its injection.

Diodrast is available in concentrations of both 35 and 70 per cent. It is an organic iodine compound which is readily excreted by the kidneys. It is nontoxic except in rare cases of sensitivity. Immediately after injection it produces a sen-

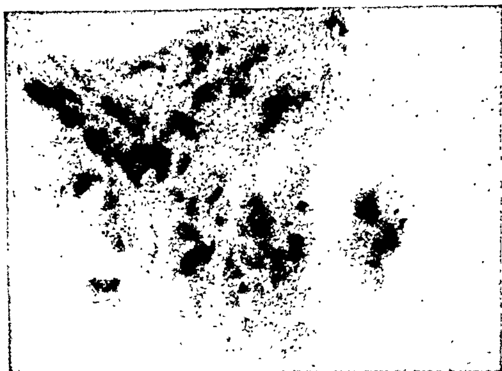


Fig. 14.—Autoradiograph obtained from tissue of thorotrastoma.
(Courtesy of Dr. Reilly and Dr. White, Radioisotope Unit, Veterans Administration Hospital, San Francisco.)



Fig. 15.—Extravasation of 35 per cent diodrast into the femoral ...

FIG. 12.—Operative findings in a patient six years after extravasation of 20 cc. of thorotrast about the femoral artery. The major arteries were found to be so friable that suture was impossible so that the profunda femoris had to be ligated and the involved segment of the superficial femoral artery replaced by vein graft, as illustrated.
(Courtesy of Veterans Administration Hospital, San Francisco.)

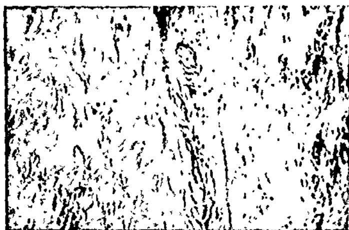


FIG. 13.—Histologic section from a thorotrastoma, showing hyalinized connective tissue and a brownish crystalline foreign body in the cytoplasm of macrophages. There is moderate lymphocytic infiltration. (H. and E., × 220).
(Courtesy of Dr. Moon and Veterans Administration Hospital, San Francisco.)

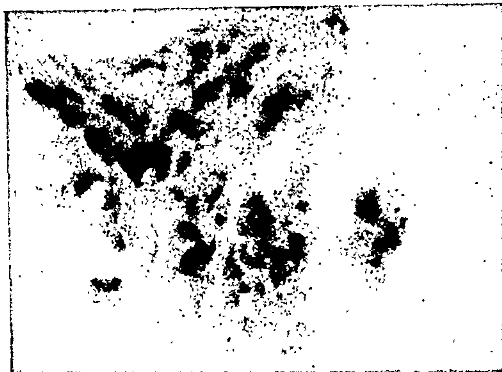


Fig. 14.—Autoradiograph obtained from tissue of thorotrastoma.
(Courtesy of Dr. Reilly and Dr. White, Radioisotope Unit, Veterans Administration Hospital, San Francisco.)



Fig. 15.—Extravasation of 35 per cent diodrast into the femoral region.

Fig. 12.—Operative findings in a patient six years after extravasation of 20 cc. of thorotrast about the femoral artery. The major arteries were found to be so friable that suture was impossible so that the profunda femoris had to be ligated and the involved segment of the superficial femoral artery replaced by vein graft, as illustrated.

(Courtesy of Veterans Administration Hospital, San Francisco.)

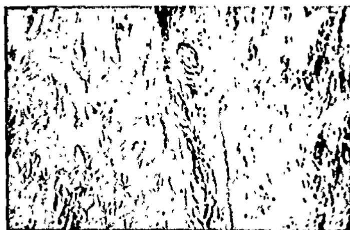


Fig. 13.—Histologic section from a thorotrastoma, showing hyalinized connective tissue and a brownish crystalline foreign body in the cytoplasm of macrophages. There is moderate lymphocytic infiltration. (H. and E., × 220).

(Courtesy of Dr. Moon and Veterans Administration Hospital, San Francisco.)

tion, a right carotid arteriogram was performed. As can be seen in the illustration, the dye passed into the right vertebral artery in high concentration. The patient subsequently developed signs of brain stem damage comparable to those seen in thrombosis of the posterior inferior cerebellar artery. Complete recovery fortunately took place within a few days. In another patient with an aneurysm of the arch of the aorta, an attempt was made to visualize the aneurysm by retrograde arteriography through the left carotid artery, using the Valsalva maneuver. Sufficient dye passed in a retrograde fashion to visualize the origin of the aorta and filled the innominate, the right subclavian, and the carotid arteries.



FIG. 17.—Roentgenogram obtained by a right retrograde carotid arteriogram with the Valsalva maneuver, showing obliterated subclavian, axillary, and brachial arteries and passage of 70 per cent diodrast into the right vertebral artery.
(Freeman, N. E., et al.: *Ann. Surg.*, *130*:398, 1949.)

Twenty seconds later the patient had a severe generalized convulsion followed by coma and aphasia which lasted for several days. This complication was successfully treated by the administration of oxygen and nicotinic acid—100 mg. every four hours. The possibility of stellate block under such circumstances should be considered.

The use of the Valsalva maneuver is not without its dangers since during the period of thoracic compression the cardiac output and blood pressure drop

femoral region. Figure 16 shows the same area two hours later. The development of severe local pain with vasospasm may be treated by the local application of heat to the injection site and, if the vasospasm persists, by a sympathetic block of the appropriate ganglia.



FIG. 16.—Decrease in the amount of 35 per cent diodrast two hours after extravasation into the femoral region.

In an occasional patient with severe ischemia of an extremity, sufficient vasospasm may be produced to cause additional thrombosis and resultant gangrene. We have encountered 2 instances of this nature. An additional 9 cases were reported by Wagner. Seventy per cent diodrast furnishes an even more opaque shadow, but at the same time is more irritating. Its use has been limited, in our experience, to visualization of the thoracic and abdominal aorta and its major branches. *Especial care should be taken to prevent the 70 per cent diodrast from reaching the intracranial circulation since convulsions and death have been not infrequently encountered.* Figure 17 illustrates a pertinent case. This patient had sustained an occlusion of the right axillary artery secondary to a surgical procedure. In an effort to demonstrate the location and extent of the arterial obstruc-

when there are clear indications that the information to be obtained will be of benefit either in the diagnosis or treatment of the patient. During the past year 125 arteriograms were made of which 25 were of the retrograde variety, using the Valsalva maneuver. Complications were encountered in only 7.

Thorotrast should be used for arteriography only with adequate exposure of the vessel so that extravasation is prevented. Again, it should be used only in those cases whose life expectancy is such that the danger of radioactivity from thorium and mesothorium are of no significance. Its use has generally been restricted to the visualization of the intracranial circulation, which is

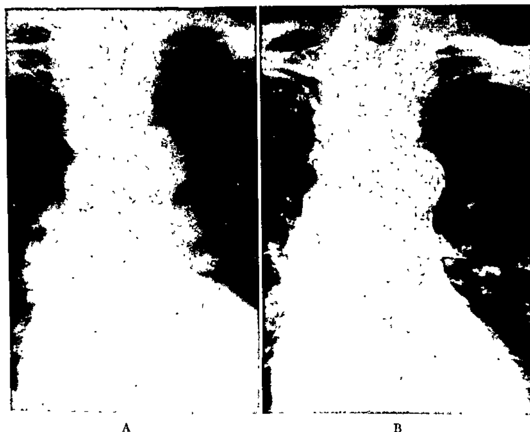


Fig. 19.—Roentgenogram of the chest. (A) Preoperative film. (B) Film made 10 days after retrograde carotid arteriogram, showing residual thorotrast in the wall of the aorta. (Freeman, N. E., et al.: *Ann. Surg.*, *130*:398, 1949.)

beyond the scope of this article, and in those patients with advanced obliterative arterial disease where it is felt that the spasm from the injection of 35 per cent diodrast may lead to the development of gangrene and in those whose life expectancy, from the standpoint of their systemic cardiovascular disease, renders the radiation danger of little significance.

The use of sodium iodide should be limited to direct aortography where a high concentration of heavy density in a small volume is essential. Even here, with a pressure injection apparatus, 70 per cent diodrast can probably be safely substituted.

significantly. In those patients with borderline circulation to the brain and heart, there is danger of intravascular thrombosis. In addition, after release of the breath, as Smithwick pointed out, there is an overswing of the blood pressure, especially in patients with hypertension. Figure 18 illustrates the height to which the blood pressure can climb after the Valsalva maneuver, before and after lumbodorsal splanchnicectomy. In our early experience with this maneuver, a complication of this nature may have occurred, as illustrated in Fig. 19. This patient had a left popliteal aneurysm and one in the lower abdomen. Eight hours after the arteriogram the patient had a sudden onset of severe precordial

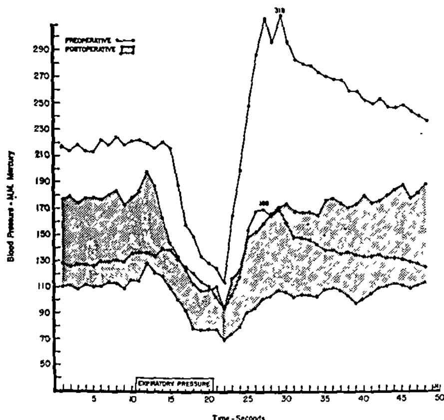


FIG. 18.—Blood pressure response to the Valsalva maneuver before and after lumbodorsal splanchnicectomy.
(Smithwick. R. H.: *Ann. Surg.*, 130:415, 1949.)

distress with a fall in blood pressure and other signs of acute myocardial infarction. Ten days later, however, when a routine roentgen film of the chest was taken, it was possible to see an accumulation of the contrast medium in the wall of the arch of the aorta, suggesting the possibility that he had developed a dissecting aneurysm of the thoracic aorta at the time of the examination. Recovery finally took place.

These mishaps from the use of arteriography, especially 70 per cent diodrast, with the Valsalva maneuver, are given special attention merely to emphasize the fact that this procedure is not without danger and that it should be used only

1 spool No. 60 cotton
1 spool No. 100 cotton
4 rubber bands
2 segments of plasma tubing, 10" long, cut at 45° angle
1 length of 5-0 silk suture with threaded needle for repair of artery
Sterile ampules of contrast media or contrast solution

Before exposing the patient to the discomfort and possible danger of arteriography, it is wise to check the peripheral pulses carefully to determine, as far as possible, the patency of the arteries to be studied. The use of an oscillometer or even a simple aneroid blood pressure manometer is of help in localizing the point of arterial obstruction.

Position of the Patient and the Extremity. Since the majority of arteriograms are made by injection of the radiopaque solution into the brachial artery just above the elbow and into the femoral artery at the groin, it is helpful to place the extremity in a position of hyperextension in order to bring the artery close to the surface and to fix it by the tension of the surrounding tissues. A pillow beneath the buttocks or a pad beneath the elbow will render the artery more accessible.

Direct Puncture. With the fingers of the left hand the most easily accessible portion of the artery is palpated and a skin wheal of novocain raised to 1½ inches above this point. With a 22 gauge needle, 1½ inches long, the subcutaneous tissues are infiltrated down to the artery. The anesthetic solution should be used sparingly so as not to obscure the pulsations of the artery. An 18 gauge needle, 3 inches long, is then introduced through the skin wheal at an angle of approximately 60 degrees; this needle should have a moderately short bevel. It should be introduced without being attached to a syringe so that its entrance into the artery can immediately be recognized. The loss of a few cubic centimeters of blood from the artery is of no significance in comparison to the importance of being sure that the entire end of the needle is lying freely within the lumen of the artery. As the needle is gradually advanced, the systolic thrusts of the artery can frequently be felt. The needle should be advanced slowly and steadily until it suddenly penetrates the arterial wall and a brisk backflow of blood comes from the hub of the needle. The hub of the needle should then be depressed and the needle advanced an additional centimeter to be certain that the point lies within the lumen. While the needle is steadied with the left hand, the rubber tubing, which is attached to the syringe being held by an assistant, is attached to the hub of the needle. The flow of arterial blood into the syringe is evident by the fact that the needle is still within the artery. The operator should then have his hand covered by a sheet of lead plate or he should grasp the needle with a long clamp in order to prevent unnecessary exposure of his hand to the x-ray beam. When all is in readiness, the operator gives the signal for his assistant to inject the contrast medium. This injection should be done as rapidly as possible, with one hand on the plunger and the other hand on the barrel of the syringe. The segment of rubber tubing which connects the syringe with the needle is of great help in preventing accidental dislodgment of the needle from the artery during the forceful injection. Serial roentgen films are taken either during the injection or immediately following it, depending on the location of the artery to be

TECHNIC OF ARTERIOGRAPHY

Equipment. The following is a list of the equipment necessary for the performance of arteriography:

(1) Without cut-down:

Antiseptic solutions for preparing the skin
1 per cent procaine
Medicine glass
5 cc. syringe for local anesthesia
Hypodermic needle
22 gauge needle, 1½"
18 gauge needle, 3"
20 cc. syringe with luer-lok
Segment of rubber tubing, preferably pressure tubing, fitted with adapter on one end to fit into the luer-lok and luer-lok connection on distal end for the needle. The adapters on either end should be fastened to the rubber tubing with heavy braided silk or wire.
50 cc. syringe
Sterile mineral oil
Gauze sponges
Sterile rubber gloves

(2) Cut-down arteriogram:

Antiseptic solutions for preparing the skin
1 per cent procaine
Small flask of sterile mineral oil
Sterile sheet with a hole in the center approximately 8 inches in diameter (N.B.: Instead of applying the drapes to the skin by means of skin clamps, it is advisable to sew the drapes to the skin so that the clamps will not be visualized on the x-ray plates).
5 cc. syringe for local anesthesia
20 cc syringe with luer-lok
50 cc. syringe with luer-lok
Medicine glass for novocain
Sponges
Sterile gloves
Scalpel with regular blade
Scalpel with No. 11 blade
1 pair tissue forceps, 4"
1 pair smooth forceps, 4"
1 pair Adson fixation forceps
1 pair straight suture scissors
1 pair gallbladder or Lahey scissors
4 mosquito hemostats, straight
2 mosquito hemostats, curved
1 Mixter gallbladder clamp, curved
2 Wheatlander retractors, self-retaining
1 vein retractor
1 curved Kelly
1 straight Kelly
1 needle holder
Needles: 2 straight skin needles
4 curved, round needles
1 small French eye, full curve needle

is inserted, inclined at a 30 degree angle toward the midline, until the lateral aspect of the vertebra is encountered. The angle of the needle is then successively altered until the point of the needle can be felt to pass just lateral to the body of the vertebra. The needle is then advanced until the posterior aspect of the aorta is encountered when a slight thrust may be felt, followed by the appearance of a pulsating stream of arterial blood. The needle should then be advanced an additional centimeter to be certain that it is well within the lumen of the aorta. In order to be certain that the point of the needle is freely in the vessel, the 5 cc. syringe containing the novocain can be attached and a small quantity of fluid injected. The needle is then connected by means of the segment of rubber tubing to the 50 cc. syringe which is lying in the cradle of the special injection apparatus. Three to 5 atmospheres of pressure are then applied and roentgen films are taken during the injection of the solution. The tubing is then detached and the needle withdrawn.

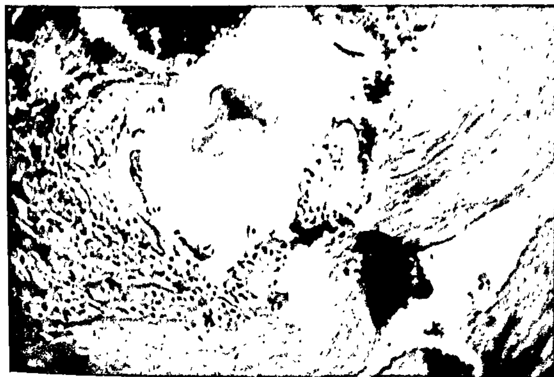


Fig. 20.—Microphotograph of wall of aorta five days after aortography, using an 18 gauge needle.

Complications: After the use of 70 per cent diodrast for aortography no complications have been encountered which were due to the solution. In one instance, a pneumothorax occurred after insertion of an 18 gauge needle through the 11th interspace. The patient developed dyspnea and a paradoxical pulse. The presence of the pneumothorax was confirmed by radiography and spontaneous recovery took place after aspiration of the air. In a large series of injections reported by Doss, Wagner, and others, no secondary bleeding has been reported. Figure 20 shows the appearance of the wall of the aorta at the site of the injection through an 18 gauge needle in a patient who died of other causes five days after

visualized and the volume of flow of blood in this vessel. At the conclusion of the exposure, blood is aspirated into the syringe to check on the position of the needle. The needle is then withdrawn and firm pressure is made over the point of puncture for two minutes.

As soon as the diodrast reaches the smaller vessels, an intense burning sensation is produced; but the patient has previously been warned to remain immobile. The skin frequently becomes blanched with cyanotic spots and subsequently flushing takes place. Within half a minute or so the patient frequently experiences a wave of heat over the entire body and a sense of nausea.

Extravasation of diodrast is associated with intense pain in the region close to the injection and frequently with arterial spasm in the distal part of the extremity. The solution, however, is rapidly absorbed and in only rare cases is this complication dangerous.

If there is no evidence of extravasation of blood at the site of the arterial puncture, the patient can be allowed to get up and walk within five minutes of the time of the injection.

Cut-down Arteriography. After infiltration of the skin and subcutaneous tissues with novocain, the artery is exposed by sharp dissection, as described in an earlier section. In the case of small vessels, a curved fine hemostat is passed beneath the vessel and a rubber band is drawn about the artery. In larger vessels, a Mixter gallbladder clamp is used and a short segment of soft rubber tubing with an outside diameter of approximately 6.5 thirty-seconds of an inch is drawn about the vessel. The artery is then raised from its bed and freed from its attachment for a distance of several centimeters. A 15, 16, or 18 gauge needle is thrust into the artery as it is held up by the elastic band or tubing, and, when all is in readiness, the contrast material is injected as rapidly as possible by the assistant while the artery is occluded by drawing up on the encircling band. After completion of the exposure, the needle is withdrawn and the artery again snugged up for a brief period to allow the puncture wound of the vessel to close spontaneously. If bleeding persists, especially after the use of a 15 gauge needle, a second rubber tube is passed about the artery and with both proximal and distal control the opening in the vessel is closed with a figure-of-eight stitch of 5-0 silk, as described in an earlier section. While the films are being developed the wound is closed, but the field is uncontaminated until after it has been determined whether the films are entirely satisfactory or not.

In performing retrograde arteriography a large needle, even up to a 13 gauge, is used and, during the Valsalva maneuver, the proximal artery is palpated with the left index finger during the period of forced expiration with the glottis closed until the force of the pulse can be felt to be markedly decreased. The injection is then made as rapidly as possible. The patient is told to bear down during exposure of all of the films and is then instructed to breathe.

Aortography. In addition to the equipment used for direct puncture arteriography, a special needle, 18 or 17 gauge, 6 inches in length, is necessary. With the patient lying in the prone position and after preparation of the skin, a skin wheal of novocain is injected 4 fingerbreadths from the spinous process just below the 12th rib or the 11th interspace in case visualization of the upper abdominal aorta is desired. After preliminary infiltration of the deeper tissues, the needle

is inserted, inclined at a 30 degree angle toward the midline, until the lateral
aspect of the vertebra is encountered. The angle of the needle is then successively
altered until the point of the needle can be felt to pass just lateral to the body
of the vertebra. The needle is then advanced until the posterior aspect of the
aorta is encountered when a slight thrust can be felt, followed by the appearance
of a pulsating stream of arterial blood. The needle should then be advanced an
additional centimeter to be certain that it is well within the lumen of the aorta.
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are taken during the injection of the solution. The tubing is then detached and the
needle withdrawn.

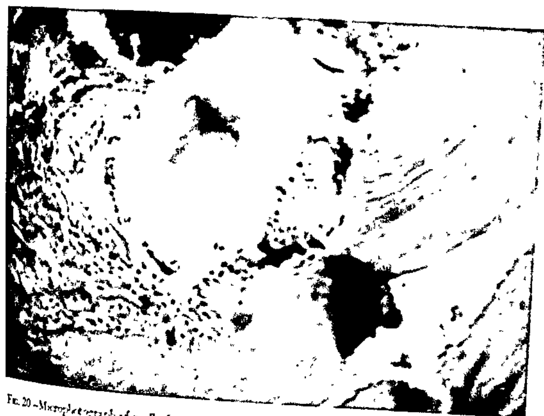


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If there is no evidence of extravasation of blood at the site of the arterial puncture, the patient can be allowed to get up and walk within five minutes of the time of the injection.

Cut-down Arteriography. After infiltration of the skin and subcutaneous tissues with novocain, the artery is exposed by sharp dissection, as described in an earlier section. In the case of small vessels, a curved fine hemostat is passed beneath the vessel and a rubber band is drawn about the artery. In larger vessels, a Mixter gallbladder clamp is used and a short segment of soft rubber tubing with an outside diameter of approximately 6.5 thirty-seconds of an inch is drawn about the vessel. The artery is then raised from its bed and freed from its attachment for a distance of several centimeters. A 15, 16, or 18 gauge needle is thrust into the artery as it is held up by the elastic band or tubing, and, when all is in readiness, the contrast material is injected as rapidly as possible by the assistant while the artery is occluded by drawing up on the encircling band. After completion of the exposure, the needle is withdrawn and the artery again snugged up for a brief period to allow the puncture wound of the vessel to close spontaneously. If bleeding persists, especially after the use of a 15 gauge needle, a second rubber tube is passed about the artery and with both proximal and distal control the opening in the vessel is closed with a figure-of-eight stitch of 5-0 silk, as described in an earlier section. While the films are being developed the wound is closed, but the field is uncontaminated until after it has been determined whether the films are entirely satisfactory or not.

In performing retrograde arteriography a large needle, even up to a 13 gauge, is used and, during the Valsalva maneuver, the proximal artery is palpated with the left index finger during the period of forced expiration with the glottis closed until the force of the pulse can be felt to be markedly decreased. The injection is then made as rapidly as possible. The patient is told to bear down during exposure of all of the films and is then instructed to breathe.

Aortography. In addition to the equipment used for direct puncture arteriography, a special needle, 18 or 17 gauge, 6 inches in length, is necessary. With the patient lying in the prone position and after preparation of the skin, a skin wheal of novocain is injected 4 fingerbreadths from the spinous process just below the 12th rib or the 11th interspace in case visualization of the upper abdominal aorta is desired. After preliminary infiltration of the deeper tissues, the needle

is inserted, inclined at a 30 degree angle toward the midline, until the lateral aspect of the vertebra is encountered. The angle of the needle is then successively altered until the point of the needle can be felt to pass just lateral to the body of the vertebra. The needle is then advanced until the posterior aspect of the aorta is encountered when a slight thrust may be felt, followed by the appearance of a pulsating stream of arterial blood. The needle should then be advanced an additional centimeter to be certain that it is well within the lumen of the aorta. In order to be certain that the point of the needle is freely in the vessel, the 5 cc. syringe containing the novocain can be attached and a small quantity of fluid injected. The needle is then connected by means of the segment of rubber tubing to the 50 cc. syringe which is lying in the cradle of the special injection apparatus. Three to 5 atmospheres of pressure are then applied and roentgen films are taken during the injection of the solution. The tubing is then detached and the needle withdrawn.

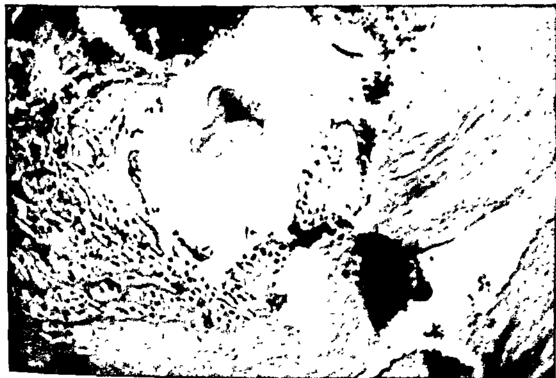


FIG. 20.—Microphotograph of wall of aorta five days after aortography, using an 18 gauge needle.

Complications: *After the use of 70 per cent diodrast for aortography no complications* have been encountered which were due to the solution. In one instance, a pneumothorax occurred after insertion of an 18 gauge needle through the 11th interspace. The patient developed dyspnea and a paradoxical pulse. The presence of the pneumothorax was confirmed by radiography and spontaneous recovery took place after aspiration of the air. In a large series of injections reported by Doss, Wagner, and others, no secondary bleeding has been reported. Figure 20 shows the appearance of the wall of the aorta at the site of the injection through an 18 gauge needle in a patient who died of other causes five days after

aortography with an 18 gauge needle. As can be seen, there was slight ecchymosis beneath the adventitia and minimal trauma in the wall of the aorta. The possibility of dislodging an aortic plaque has been anticipated, but no such complication has as yet been reported. We have felt it wise to have the patient admitted to the hospital in order to have this examination performed.

Pressure Injection Apparatus. A simple form of pressure injection apparatus is illustrated in Fig. 21. A carbon dioxide cylinder is fitted with a needle valve and pressure gauge. Heavy rubber tubing capable of withstanding a pressure of 10 atmospheres leads to a pipe fitted with a Lunkenheimer valve. A release valve is placed in the circuit and then a grease gun. A small segment of sponge rubber is applied to the piston of the grease gun which is brought into contact with the plunger of the 50 cc. syringe. The syringe lies in a cradle with the tip projecting

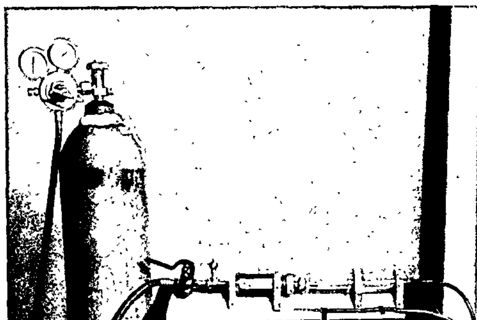


Fig. 21.—Pressure injection apparatus; accurately tooled cylinder and piston from a grease gun.

through an aperture. The 50 cc. syringe is equipped with a luer-lok for connection to the rubber tubing, which is then connected to the needle by another luer-lok connection. Only the syringe, rubber tubing, and needle are sterilized.

In actual operation, after the syringe has been filled with the contrast medium. the rubber tube and needle attached, it is well to test for leaks by closing the tip of the needle temporarily with the finger while the pressure is temporarily applied through the injection apparatus.

The present rapid cassette changer which has been so successful is a modification of one described by M. McGregor in the August 1949 issue of the *British Journal of Radiology*.

It is a gravity-fed magazine type with the plunger actuating a cassette stop on the push and a micro switch for the exposure on the pull.

From five to eight 14 × 17 cassettes are used and these

intervals of one to one-half seconds, depending on the operator. However, for the majority of the peripheral vessels this speed is not necessary. It is quite often advantageous to begin rapidly and after the second film to lengthen the intervals between the following exposures. This may be necessary to show filling in cases with diseased, occluded, or spastic arteries.

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